PROCEEDINGS FROM A WORKSHOP ON ECOLOGICAL CARRYING CAPACITY OF SALMONIDS IN THE COLUMBIA RIVER BASIN: MEASURE 7.1A OF THE NORTHWEST POWER PLANNING COUNCIL'S 1994 FISH AND WILDLIFE PROGRAM

REPORT 3 OF 4
FINAL REPORT

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PREFACE

This report is one of four that the Pacific Northwest National Laboratory (PNNL) staff prepared to address Measure 7.1 A in the Northwest Power Planning Council's (Council) Fish and Wildlife Program (Program) dated December 1994 (NPPC 1994). Measure 7.1 A calls for the Bonneville Power Administration (BPA) to fund an evaluation of salmon survival, ecology, carrying capacity, and limiting factors in freshwater, estuarine, and marine habitats. Additionally, the Measure asks for development of a study plan based on critical uncertainties and research needs identified during the evaluation. This report presents the proceedings of a workshop that was held in Portland, Oregon during September 6 and 7,1995. Ten experts in the field of carrying capacity discussed the definitions of carrying capacity, the determinants of carrying capacity, the research needs to increase the region's understanding of the ecology, carrying capacity, and limiting factors of salmon. The report ends with conclusions and recommendations for studying carrying capacity. Three other reports were prepared based on the work addressing Measure 7.1 A:

1. "Evaluation of Carrying Capacity: Measure 7.1 A of the Northwest Power Planning Council's 1994 Fish and Wildlife Program, Report 1 of 4."
2. "Study Plan For Evaluating Carrying Capacity, Measure 7.1 A of the Northwest Power Planning Council's 1994 Fish and Wildlife Program, Report 2 of 4."
3. "A Literature Review, Bibliographic Listing, And Organization of Selected References Relative To Pacific Salmon (Oncorhynchus spp.) And Abiotic And Biotic Attributes Of The Columbia River Estuary And Adjacent Marine & Riverine Envioms, for Various Historical Periods, Measure 7.1 A of the Northwest Power Planning Council's 1994 Fish and Wildlife Program, Report 4 of 4."

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Our sincere thanks to the people who helped with this study. Dr. Mark Schneider, formerly of BPA, wrote the statement of work that started the study. Nora Berwick and John Marsh of Council staff helped interpret Measure 7.1A. Tom Vogel of BPA was the contracting officer's technical representative for the project after Dr. Schneider moved to the National Marine Fisheries Service.

Elaine Cogan of Cogan. Owens, Cogan in Portland, Oregon was the workshop facilitator. Amy Groppo and Devin Williams of Moore & Henderson in Portland, Oregon made video and audio recordings of the workshop.

We thank the Steering Committee: Duane Anderson, Pacific States Marine Fisheries Commission; Jack Donaldson, Columbia Basin Fish & Wildlife Authority; Gordon Haugen, USDA Forest Service; Steve Hays, Chelan County Public Utility District; Jim Lichatowich, Independent Scientific Group; Michael Schiewe, National Marine Fisheries Service: Don Yon, Oregon Department of Environmental Quality. They were the organizing body. They were responsible for communicating committee actions to their respective agencies. The Steering Committee delineated the purpose and scope of the workshop. advised on its content and format, provided guidance on prospective expert panelists. and helped coordinate various workshop-related activities.

We especially thank the experts: Peter Bisson, USDA Forest Service; Dan Bottom. Oregon Department of Fish & Wildlife; Charles Coutant, Oak Ridge National Laboratory: Kyle Hartman. State University of New York; Dale McCullough, Columbia River Inter-Tribal Fish Commission; Lars Mobrand, Mobrand Biometrics, Inc.; Bill Pearcy, Oregon State University; Reg Reisenbichler, National Biological Service; Charles Simenstad and Robert Wissmar, University of Washington. They came to Portland, Oregon to discuss carrying capacity Their ideas, suggestions. and knowledge of the subject were used in our evaluation of carrying capacity (Neitzel and Johnson 1996a) and in the development of a study plan for carrying capacity(Neitze1 and Johnson 1996a,b).

ABSTRACT

This report contains the proceedings of a workshop held during 1995 in Portland, Oregon. The objective of the workshop was to assemble a group of experts that could help us define carrying capacity for Columbia River Basin salmonids. The workshop was one activity designed to answer the questions asked in Measure 7.1 A of the Council's Fish and Wildlife Program (NPPC 1994). Based. in part, on the information we learned during the workshop we **concluded that the approach inherent in 7.1A will not increase understanding of ecology, carrying capacity, or limiting factors that influence salmon under current conditions.** Measure 7.1 A requires a definition of carrying capacity and a list of determinants (limiting factors) of capacity. The implication or inference then follows that by asking what we know and do not know about the determinants will lead to research that increases our understanding of what is limiting salmon survival. It is then assumed that research results will point to management actions that can remove or repair the limiting factors. Most ecologists and fisheries scientists that have studied carrying capacity clearly conclude that this approach is an oversimplification of complex ecological processes. To pursue the capacity parameter, that is, a single number or set of numbers that quantify how many salmon the basin or any part of the basin can support, is meaningless by itself and will not provide useful information.

To increase understanding of ecology, carrying capacity, and limiting factors, it is necessary to deal with the complexity of the sustained performance of salmon in the Columbia River Basin. Density independent factors affect salmon performance, as well as density dependent factors. Factors that affect performance in one part of the salmon life cycle can manifest their effect in later phases of the life cycle. Factors can have different effects on different populations in different parts of the Columbia Basin or marine environment. Factors can affect different populations or stocks in different ways. There are potential negative impacts of focusing on abundance alone (NRC 1995). For example, how do the many populations and stocks of salmon affect one another? When we understand the ecological complexity of salmon performance, the region will be better able to make decisions to improve salmon survival in the basin.

We suggest that the region evaluate carrying capacity from more than one viewpoint. Platt (1964) provides a method for scientific inquiry and Pepper (1966) provides at least four views that can be used to define capacity in a way that helps identify critical uncertainties and research needs while dealing with the complexity of salmon performance.

We recommend that the region use the contextualistic view for evaluating capacity. Capacity, from the contextual view, is a component of salmon performance, and is inseparable from diversity and productivity. To evaluate capacity, in this way, we recommend that the region compare conditions in the Columbia River Basin to historic conditions using the methods described as the Patient-Template Analysis (Lichatowich et al. 1995).

FIGURES[1]

[1] **The figures presented by the expert panel (Chapter 3) are not included in this list.**

TABLES[2]

[2] The tables presented by the expert panel (Chapter 3) are not included in this list.

CONTENTS

Chapter 1: INTRODUCTION

Measure 7.1 A in the Northwest Power Planning Council's (Council) Fish and Wildlife Program (Program) dated December 1994 calls for the Bonneville Power Administration (BPA) to fund an evaluation of salmon survival, ecology, carrying capacity,[3] and limiting factors in freshwater, estuarine, and marine habitats. The Measure has two parts (7.1 A. 1 and 7.1 A.2). The objective of (7.1 A. 1), an evaluation of carrying capacity, is to increase understanding of the ecology, carrying capacity, and limiting factors that influence salmon survival under current conditions. The second part of the Measure (7.1 A.2) asks for the development of a study plan based on the critical uncertainties and research needs identified during the evaluation of carrying capacity.

Eight specific elements are listed in Measure 7.1 A. 1 to include in the evaluation. They are:

1. Analysis of competition between non-native species and anadromous salmonids and competitive interaction resulting from hatchery management practices.
2. Estimate of current salmon carrying capacity for the Columbia River mainstem, tributaries, estuary, plume and nearshore oceans for juvenile fish.
3. Evaluation of the effects of the alteration and timing of the ocean plume on salmon survival caused by the construction and operation of the hydroelectric system.
4. Identification of residence time for juvenile salmonids and their level of smoltification.
5. Identification of management measures to protect and improve estuary habitat as well as increase the productivity of the estuary.
6. Recommendations for management responses to fluctuating estuary and ocean conditions such as adjusting total numbers of releases to take such conditions into account.
7. Identification of critical uncertainties and research needs, and estimates of incremental gains in survival from improvements in each area.
8. Monitoring program to identify optimal timing for residency in the estuary and nearshore environment.

To address all eight issues and accomplish the objective of the evaluation of capacity, we were told by Council staff to:

- Review existing data.
- Conduct a workshop.

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[3] **In this report, we use the terms: capacity, carrying capacity. and ecological carrying capacity interchangeably. Attempting to remain consistent with the intent of Measure 7. I A, we use these terms to describe** *"the upper level for a population. beyond which no major increase can* **occur" (Odum 1959). The expert panel and the authors that we cite may have other definitions for these terms or use them in a specific context with other population descriptors. We have tried very carefully to quote the expert panel and to cite the authors. We strongly suggest that readers turn to the original source for clarification.**

- Use the information from the review and the workshop to define capacity and list the determinants of capacity.
- Ask, "What do we know about the determinants of carrying capacity?'
- Ask, "What do we not know about the determinants of carrying capacity?'
- Ask, "What research can we do to understand what we do not know about carrying capacity?"
- Ask. "What management actions can we implement immediately. relative to carrying capacity. that will improve salmon survival?"
- Use the information collected and the answers to the questions to develop a study plan based on the critical uncertainties and research needs identified in the evaluation.

This approach is illustrated in Figure 1. The study plan would provide a basis to implement management actions and conduct research. Results of the research and management actions would lead to increased understanding of capacity. This in turn would produce implementation of an ecosystem approach to protect and enhance salmon in the Columbia River Basin.

We pursued answers to the questions asked in Measure 7.1 A. 1. We concluded, however, that this approach would **not** meet the objective. That is, the approach illustrated in Figure 1 would not increase understanding of ecology, carrying capacity, or limiting factors that influence salmon under current conditions. Responding to the elements in Measure 7.1 A. 1 requires a specific definition of carrying capacity and a list of determinants (limiting factors) of capacity. The information that we learned during the workshop and from our review of ecological literature led us to the conclusion that the proposed approach breaks down (Figure 2) if one attempts to define capacity as a simple ecological parameter (Odum 1959, Reeves et al. 199 1).

The capacity parameter. that is. a single number or set of numbers that quantifies how many salmon the basin or any part of the basin can support. will not provide useful information. To increase understanding of ecology, carrying capacity. and limiting factors. it is necessary to deal with the complex interrelationships among the characteristics of salmon performance, including diversity. capacity, and productivity (Paulik 1973. Hankin and Healey 1986, Moussalli and Hilbom 1986, Hilbom and Walters 1992. Mobrand et al. in press). Accordingly. we revised the approach to evaluate capacity (Figure 3). The approach we used followed the work on scientific discovery by Platt (1964) and the work on world hypotheses by Pepper (1966). The approach illustrated in Figure 3 was used in our evaluation (Neitzel and Johnson 1996a) and the development of a study plan (Neitzel and Johnson 1996b).

This report contains: a description of the workshop (Chapter 2) extended abstracts of the presentations (Chapter 3). an edited transcript of the Day-2 question and answer session (Chapter 4). and our conclusions and recommendations to the region for studying carrying capacity (Chapter 5). The books. journal articles, and technical reports we cite in this report are referenced in Chapter 6.

Several other activities are part of this study. We completed an evaluation of carrying capacity. We outlined necessary elements of a study plan to define the critical uncertainties and research needs related to carrying capacity in the Columbia Basin. We reviewed existing data to determine what is known and not known about the determinants of carrying capacity in the Columbia Basin, with focus on the estuary. The results of these activities are presented in separate reports to BPA.

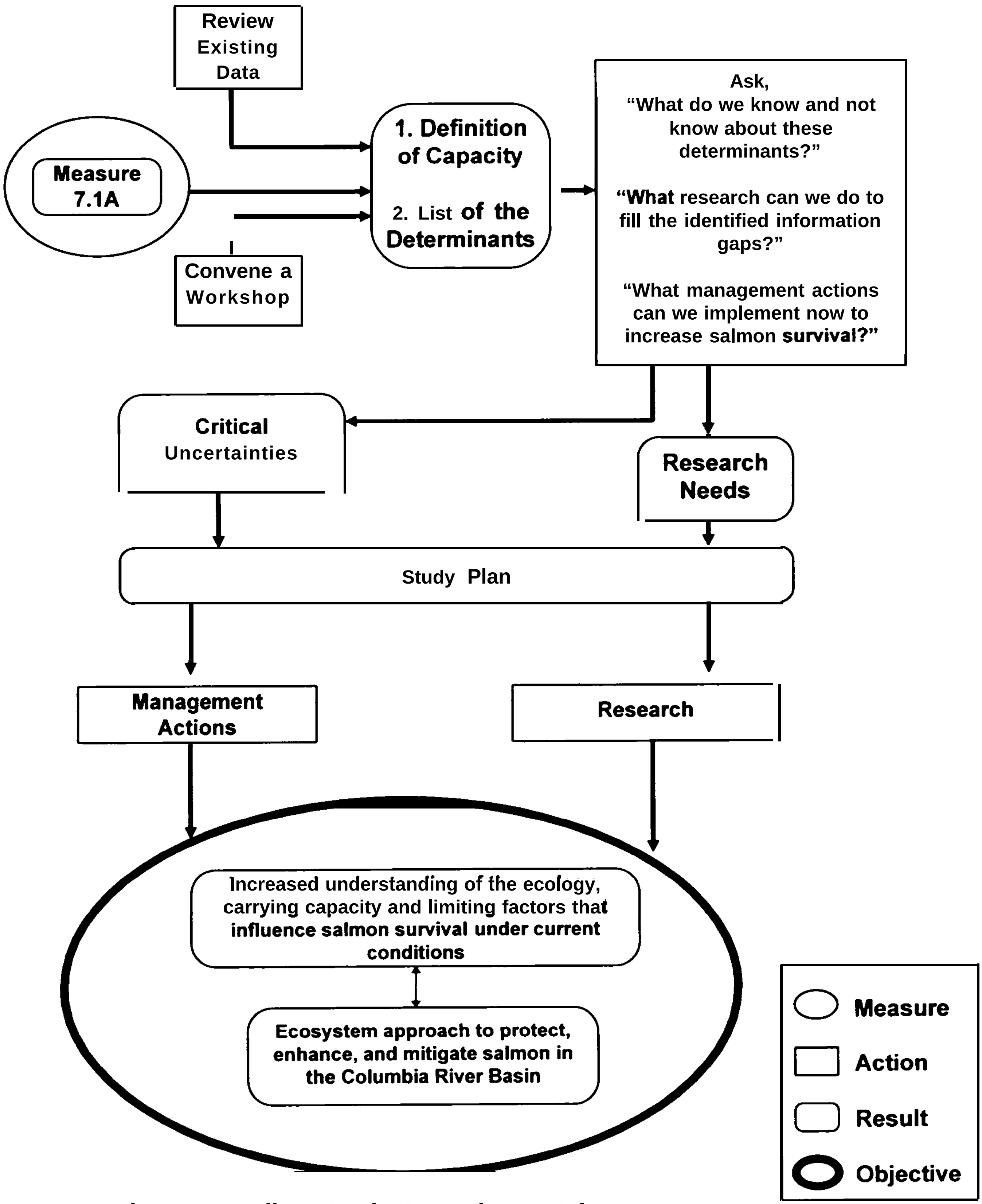

Figure 1. Flow Diagram Illustrating the Approach We Tried to Use to Analyze Carrying Capacity and Develop a Study Plan.

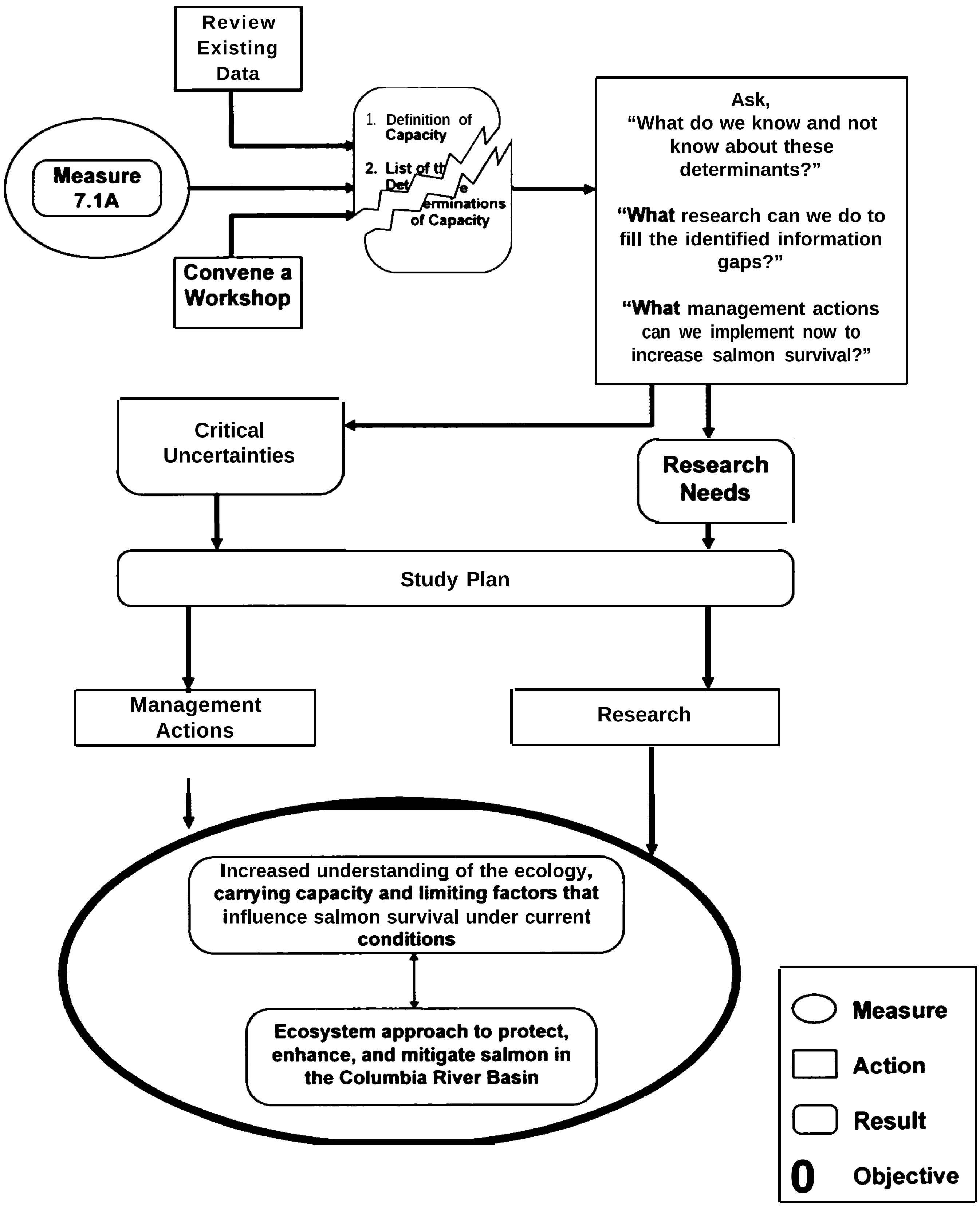

Figure 2. Flow Diagram Illustrating the Breakdown in the Approach We Tried to Use to Analyze Carrying Capacity and Develop a Study Plan.

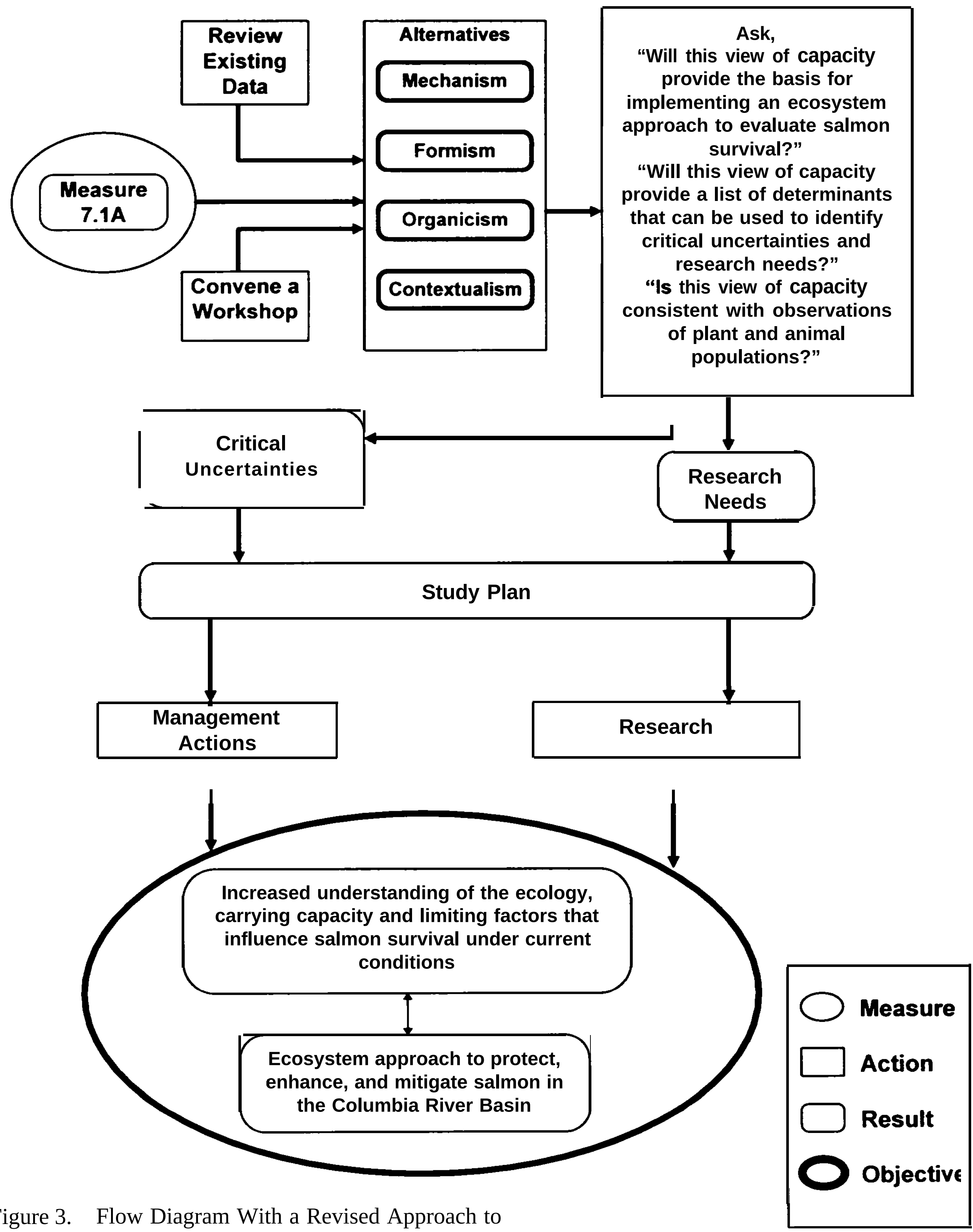

Figure 3. Flow Diagram With a Revised Approach to Analyze Carrying Capacity and Develop a Study Plan.

Chapter 2: Workshop

To collect the necessary information to address the elements and questions in Measure 7.1 A, the Bonneville Power Administration (BPA) contracted with Pacific Northwest National Laboratory (PNNL) to convene a workshop on ecological carrying capacity of salmonid habitats in the Columbia River Basin. This proceedings documents the discussion and results of the workshop that was held on September 6 and 7, 1995 in Portland. Oregon. The scope of the workshop was to provide a forum for regional and national experts to share information and ideas on what we know and do not yet know about the carrying capacity of freshtvater, mainstem, estuarine. and ocean habitats, particularly as it relates to salmonids in the Columbia River Basin. The incentive for esperts to participate in the workshop was not only the dialogue it provided between scientists and policy makers. but also the opportunity to influence the formulation of a study plan for the Council's review and approval to be prepared by PNNL.

Workshop Approach

The initial step in developing the W'orkshop was to form a Steering Committee. PNNL invited members from the Council and various commissions and agencies, including the Columbia Basin Fish & Wildlife Authority (CBFWA), Columbia River Inter-Tribal Fish Commission (CRITFC), the Bi-State Estuary Commission, Pacific States Marine Fisheries Commission. Columbia River Estuary Study Task Force (CREST). Columbia River Estuary Data Development Program (CREDDP), Public Power Council (PPC). Pacific Northwest Utilities Conference Committee (PNUCC), USDA Forest Service and National Marine Fisheries Service, to participate on the Steering Committee. Participation by the fishery agencies and Tribes was actively sought. Members were selected by BPA in consultation with the Council and CBFWA. The Steering Committee was an organizing body, not a policy body, whose members were responsible for communicating committee actions to their respective agencies. The Steering Committee delineated the purpose and scope of the workshop, advised on its content and format. provided guidance on prospective expert panelists. and helped coordinate various workshop-related activities.

Steering Committee

The Steering Committee (Table 1) supported the convening of an expert panel of ecologists and biologists at the Carrying Capacity Workshop. Using a list of names provided by the Steering Committee. PNNL solicited and organized the involvement of ten carrying capacity experts from inside and outside the Columbia River Basin. Criteria for selecting the expert panelists included:

I. Regional scientist or administrator familiar with or working with carrying capacity issues.
2. Academic scientist working with carrying capacity issues.
3. Individual who has published peer-reviewed articles or books on the subject of carrying capacity.
4. Individual recommended by the Steering Committee, BPA, or the Council.

Table 1. Steering Committee for Ecological Carrying Capacity Workshop	
Committee Members	
Name	**Affiliation**
Duane Anderson	Pacific States Marine Fisheries Commission
Jack Donaldson	Columbia Basin Fish & Wildlife Authority
Gordon Haugen	USDA Forest Service
Steve Hays	Chelan County Public Utility District
James Lichatowich	Independent Scientific Group
Michael Schiewe	National Marine Fisheries Service
Don Yon	Bi-State Estuary Commission
Ex Officio Members	
Name	**Affiliation**
Nora Berwick	Northwest Power Planning Council
Duane Neitzel	Pacific Northwest National Laboratory
Thomas Vogel	Bonneville Power Administration

We organized the workshop's expertise around four main habitat types: tributaries. mainstem. estuary, and ocean. The strength of the expert panel constituted the framework upon which the workshop was structured. we asked the expert panelists for their informed professional opinions, i.e.. what they believe about carrying capacity. how they came to believe it, and what experiences and obsenations. data, and literature support their beliefs. This holistic expertise infused a broad. in-depth understanding of ecological carrying capacity into the process of addressing the Council's concerns about carrying capacity. In addition. the design of the Workshop included routine question-and-answer periods to provide optimal opportunities for audience participation. The panelists are listed in Table 2.

Workshop Format

On the first day of the workshop. each expert panelist gave a 30-minute presentation. including time for questions and answers. The presentations allowed each panelist an opportunity to share their knowledge and explain their views on ecological carrying capacity. with emphasis on a particular habitat (tributary. mainstem. estuary. ocean). Panelists were asked to address at least one of the six critical questions listed below. Prior to the workshop. each panelist provided a 2-5 page extended abstract of their talk (see Chapter 3).

Table 2. Expert Panel for Ecological Carrying Capacity Workshop	
Name	**Affiliation**
Peter Bisson	USDA Forest Service
Daniel Bottom	Oregon Dept. of Fish & Wildlife
Charles Coutant	Oak Ridge National Laboratory
Kyle Hartman	State University of New York
Dale McCullough	Columbia River Inter-Tribal Fish Comm.
Lars Mobrand	Mobrand Biometrics, Inc.
William Pearcy	Oregon State University
Reg Reisenbichler	National Biological Service
Charles Simenstad	University of Washington
Robert Wissmar	University of Washington

- What hypotheses underlie an understanding of salmon carrying capacity in the Columbia Basin?
- What do we currently know about Columbia Basin carrying capacity and how good is this knowledge?
- What are our knowledge gaps and critical uncertainties? For example, how important is competition between non-native species and anadromous fish?
- What assumptions do we make concerning this issue as it arises in other analyses and forums?
- What analytical tools are available?
- What must be accomplished to address the relationship between salmonid productivity and habitat carrying capacity?

On the second day of the workshop, panel discussion was organized into three sequential sessions. oriented specifically around the following questions.

Part 1: Scientific basis of carrying capacity

- What is carrying capacity? Provide a scientific framework for that definition. How would you explain carrying capacity to a layperson?
- What are the determinants of carrying capacity in the Columbia River system? Which are most important?
- Give examples of biotic and abiotic determinants. Which of these are limiting, and why? How do these determinants affect the survival of salmonids?

Part 2: Objectives of carrying capacity work

- What should be the objective(s) of addressing carrying capacity in the Columbia River Basin?
- Given your definition of carrying capacity. what critical uncertainties stand in the way of meeting the objective(s)?

Part 3: Carrying capacity research needed to improve salmon survival

- What carrying capacity research can we do now? What needs to be done first?
- What management actions can be taken. now and in the future?
- What determinants of carrying capacity can we monitor to evaluate actions to improve salmon survival?

Part 4: Closing words of advice to the Council

Before adjourning the workshop each of the experts were asked to address their closing remarks to the Council. They were asked to say what they think the Council should do or could do relative to carrying capacity to increase the region's understanding of the ecology. carrying capacity. and limiting factors of salmon.

CHAPTER 3: EXPERT PANEL PRESENTATIONS

On Day 1 of the workshop, each panelist gave a presentation from their area of expertise on ecological carrying capacity. The panelists provided extended abstracts of their presentations which are presented here. The tables, figures, and references are contained within the text of each abstract and are not presented or listed elsewhere in this report.

Table 3. Index of Expert Panel Presentations

Ecological carrying capacity for salmonids in tributaries of the lower Columbia River

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The lower Columbia River once held very large populations of five of the seven species of salmon in the Pacific Northwest. Prior to development of the lower Columbia River Basin by settlers from Europe and eastern North America, abundant populations of chinook, coho, and chum salmon as well as steelhead and sea-run cutthroat trout flourished in mainstem tributaries and headwater streams (Netboy 1980, Chapman 1986). Although this region supported large numbers of Native Americans in the early 19th century, the landscape was relatively unaltered by anthropogenic disturbance (with the exception of deliberately set fires; see Agee 1993). and it seems reasonable to assume that most streams and their associated riparian zones existed in a pristine condition influenced only by natural disturbances such as floods. wildfires, and windstorms. Over the last 150 years, considerable change has taken place in lower Columbia River watersheds as well as other coastal areas (Gregory & Bisson 1996, In press) and the carrying capacity for salmonids has been significantly diminished. The following discussion examines some of the more important changes that have taken place and their implications for carrying capacity restoration.

Water quantity and quality

Alteration of the natural flow characteristics of lower Columbia tributaries has been one of the most pervasive ecological changes. The operation of hydroelectric and flood control dams has shifted the duration and magnitude of high- and low-water periods in many large tributary systems. Because the hydrologic regime of lower Columbia River tributaries is dominated more by rainfall than snowmelt, many streams experience their highest flows in fall and winter. Salmonids inhabiting these systems have adapted to fall and winter storms; two of the more important adaptations include utilizing high flows for returning adults to access headwater spawning sites and for overwintering juveniles to access protected habitat along riverine floodplains. There are 26 large hydroelectric and flood-control dams in the lower Columbia Basin (Muckleston 1993). Most are located in the Willamette River drainage system, but the hydrologic regimes of the Cowlitz River and Lewis River are also affected by water storage and releases at dams. As in other parts of the Columbia River Basin, the historical trend has been to store water during periods of high runoff and to maximize hydropower production when demands are greatest (NRC 1995). Disruption of normal runoff patterns has affected the survival of salmon eggs through unseasonably high gravel scour or redd dewatering, and has impeded the ability of both juveniles and adults to gain access to habitats critical to the fulfillment of life-cycle functions. It is unlikely that the ecological carrying capacity for salmonids in tributaries of the lower Columbia can be restored unless patterns of discharge in watersheds with large dams more closely approximate natural hydrologic regimes.

Even in watersheds without dams, runoff patterns have been altered by human activity. Winter storm-flow peaks have been accentuated in drainages with extensive road networks and in small streams draining recently logged areas within the transient snow zone. i.e.. the elevation zone in which snow may accumulate and melt several times over a winter (Harr 1986). Some of the most significant increases in storm-flow runoff have been documented for urban areas and areas of heavy industrial development (Booth 1991). Increasing the frequency and magnitude of peak flows has important implications for salmonid carrying capacity. Mobilization of the streambed during peak flows, while important for renewing natural succession processes. can occur so often that the reproductive success of salmonids may be impacted and the abundance of aquatic invertebrates upon which rearing juveniles depend may be depleted. In the worst case, stream channels may be scoured so often that very little substrate remains and most of the productivity is lost (Chamberlin et al. 1991). As was the case for watersheds with dams, restoration of carrying capacity will be aided by a return to a more natural flow regime.

Water quality as well as quantity has been altered in many lower Columbia tributaries. Two of the most common changes have been an increase in the amount of suspended sediment and an increase in water temperature, especially in 1 st- to 4th-order streams. Sediment changes have resulted from a variety of factors: increased erosion rates in headwater areas (Chamberlin et al. 1991). landslides and runoff from unpaved roads (Swanson et al. 1987. Fumiss et al. 1991), loss of streambank vegetation (Platts 1991). and in-stream activities such as dredging or gravel mining (NRC 1992). Temperature increases have resulted mainly from the loss of riparian vegetation, allowing more sunlight to reach streams (Beschta et al. 1987). Typically, the greatest temperature increases are measured when the forest canopy is removed from small, headwater channels (Holtby 1988). Changes to the thermal regime associated from forest canopy removal include both maximum daily temperatures and the magnitude of the diurnal temperature fluctuation (Beschta et al. 1987).

Increases in suspended sediment and stream temperatures have altered the carrying capacity for salmonids in lower Columbia tributaries. Except for the very high sediment concentrations in the Toutle and Cowlitz rivers associated with the 1980 eruption of Mt. St. Helens, it is unlikely that suspended sediment has reached levels that would be directly harmful to salmonids (e.g., through gill abrasion), but relatively high sediment concentrations are known to impede feeding ability (Noggle 1978) and may cause behavioral avoidance leading to premature emigration by juveniles (Bisson & Bilby 1982). The effects of elevated temperatures are quite complex (Beschta et al. 1987, Hartman & Scrivener 1990) and may have both positive and negative influences on salmonid production. Limited evidence suggests that elevated temperatures tend to benefit salmonid production at northern latitudes and reduce production at southern latitudes (Gregory & Bisson. In press). In the lower Columbia Basin, the net effect of increased stream temperatures may well be negative. Introduced and native non-salmonid fishes abundant in this part of the river system, including members of the families Cyprinidae and Centrarchidae. are physiologically better adapted to warmer waters and may out-compete or prey on rearing salmonids when stream temperature is elevated (Reeves et al. 1987). Attempts to control non-salmonid predators or potential competitors in lower Columbia tributaries are likely to be ineffective without corresponding measures to restore more natural temperature regimes.

Floodplain habitat

Several species of salmon make use of seasonally flooded habitats during winter. For some species, e.g.. coho salmon, availability of floodplain habitats may constitute one of the most important factors limiting production (Peterson 1982). Riverine floodplains are frequently developed as agricultural/pasture land or as urban/industrial land. In both cases, there has been a strong trend toward isolating Pacific Northwest rivers from their floodplains through diking, channelization, streambank armoring. and channel dredging (NRC 1995). In the Willamette Valley, the highly complex network of overflow channels. sloughs. and oxbow lakes that existed in the mid-1900s has been transformed into a highly simplified single-channel river with few connections to the historical floodplain (Sedell & Froggatt 1984). Loss of floodplain habitat is proportionately greatest in urban areas where concerns over threats of flooding to life and property have clearly superseded concerns over habitat loss. In such cases, the likelihood of floodplain restoration will remain low.

Although the prospects for complete restoration of connections between rivers and their floodplains are not optimistic. there may be opportunities to allow flooding on some farmlands and other areas where rivers can interact with their floodplains without causing excessive harm to other land and water uses. In several river basins, there have been small-scale removals of portions of dikes and levees to allow flooding (NRC 1992). In areas where societal interests mandate some level of flood control, creation of artificial floodplain habitats such as off-channel ponds has been shown to enhance salmonid production (Cederholm et al. 1988). Floodplain restoration may offer one of the best opportunities for improving the carrying capacity for salmonids in tributaries of the lower Columbia river.

Instream physical habitat

Removlal of sunken logs and logjams in lower Columbia tributaries to permit boat navigation began in the mid- 19th century and continued well into the 20th century. Some of the largest logjams occurred at river mouths and provided habitat for many species, either during periods of migration or juvenile rearing. Log transport was an important use of lower Columbia tributaries during much of the 20th century, and debris removal to facilitate log rafting transformed extensive reaches of lower mainstem tributaries from structurally complex. debris-choked rivers to simplified. open channels (Sedell & Luchessa 1982). Splash damming occurred in many small tributaries as recently as the

1950s. The sudden release of stored logs when splash dams were breached effectively simulated the effects of a massive debris torrent, leading to channels being scoured down to bedrock (Bisson et al. 1987). Debris torrents originating from forested hill-slopes also increased in frequency after logging (Swanson et al. 1987) so that by the early 1960s many lower Columbia tributaries had lost much of the large woody debris they had accumulated over the last few centuries. This condition was further compounded by efforts by state fisheries agencies from the 1950s to late 1970s to remove log jams and other putative blocks to upstream fish migration (Bisson et al. 1987). Forestry operations removed trees along small streams until enactment of forest practices acts in the early 1970s. and even after this time riparian buffers of only 25-50 ft. were left along many fish-bearing streams on state and private forest lands. The combined effects of all these activities left many lower Columbia tributaries with very little woody debris relative to historical levels, and habitat for rearing salmonids became highly simplified (Bisson et al. 1992).

An indication of the extent to which rearing habitat in lower Columbia tributaries has been altered over the last 50 years has recently been shown in a comparison of the current frequencies of large. deep pools with the frequencies of pools that existed from 1935 to 1945 (Sedell & Everest 1991. FEMAT 1993). The following table compares historical vs current frequency (number per mile) of pools having an area greater than 50 yd^2 and a depth greater than 6 ft. among several lower Columbia River vvatersheds. Only two water-sheds (Wind River. Abernathy Creek) showed little change over five decades; the others exhibited pool losses of from 41% to 94%.

Table 1

	Pool frequency (number/mile)		
	1935-1945	1987-1992	Percent change
Wind River	2.1	2.3	+ 10%
Lewis River	4.6	2.7	-41%
Cowlitz River	8.1	3.4	-58%
Coweeman River	3.3	0.2	-94%
Abernathy Creek	0.4	0.4	0%
Germany Creek	0.9	0.5	-44%
Elochoman River	3.7	0.3	-84%
Gravs River	5.2	1.6	-69%

Loss of large pool habitat has likely been caused by the removal of large woody debris and large boulders. by an increase in the amount of fine sediment (sand and gravel) deposited in pool bottoms. and. in some instances. by channelization (FEMAT 1993). Large pools do not provide the full range of habitat conditions needed by all salmonids. but they are important holding areas for upstream migrating adults and serve as rearing sites for the juveniles of certain species. The observation that greater than 50% of the large pools have been lost from many lower Columbia tributaries over the last half century is indicative of the extent of physical habitat alteration, especially in light of the fact that many of these streams had already been changed by human activities when the original pool surveys were initiated.

Although there are now far fewer logjams in lower Columbia tributaries than occurred historically, there are other anthropogenic factors that inhibit or block salmonid migrations. Small dams exist on some streams. and most have no provisions for fish passage. These dams have been built to provide water for agricultural purposes and occasionally for domestic drinking water, and many are decades old (NRC 1995). Dams prohibiting upstream passage of spawning adults are frequently located at hatcheries. There has never been a comprehensive inventory of all road crossings on fish-bearing tributaries of the lower Columbia River. but the number of culverts in small streams is quite high -- perhaps in the tens of thousands (FEMAT 1993) Some of these culverts do not impede salmonid migration. but many others are either too long, too steep, too shallow, or do not possess outfalls into which fish can easily jump. Culverts that may be negotiated by adult salmon may be impassable to up-stream migrating juveniles (Fumiss et al. 1991). Restoration of the carrying capacity of lower Columbia tributaries for salmonids would benefit from watershed-level examinations of all road crossings and replacement of impassable culverts and other road-related migration blocks with passable structures.

Natural disturbances

The natural disturbance regime is the “engine” that drives the creation of habitat for salmonids and other aquatic resources. Large natural disturbances such as major floods, wildfires, windstorms. and volcanic eruptions are often considered detrimental to salmonid production. In fact, the short-term effects of a large disturbance may be quite negative: eggs may be scoured from spawning sites. logjams may be formed, sediment levels may rise temporarily. riparian shade may be lost. and aquatic invertebrates destroyed. But in many cases these large disturbances are necessary to provide the raw materials for salmonid habitat, and without them there would be a gradual decline in habitat quality. Over the last century there has been a concerted effort to control natural disturbances in the Pacific Northwest and elsewhere, an understandable effort given the potential consequences of these events for other human endeavors. Nevertheless, we are currently faced with the dilemma of extensively simplified stream systems and widespread degradation of ecological carrying capacity. How can we manage our watersheds in such a way that the long-term benefits of large natural disturbances are protected without imposing undue dangers on other activities and land uses?

Two changes in management policy would be helpful. First, we should abandon the notion that it is desirable for all streams to conform to an “ideal” condition. Streams in pristine watersheds show remarkable variation in channel morphology, substrate composition. and large woody debris levels in response to long-term cycles of disturbance and recovery (Reeves et al.. In press) -- cycles that are often centuries long. At any given time. some streams will naturally exist in a very high-quality. productive state while others will exist in various states of lower quality. relatively unproductive habitat. Over periods of tens to hundreds of years. streams change from unproductive to productive states in response to disturbance-recovery processes (Reice et al. 1990). Without natural disturbances to recharge significant structural roughness elements of the channel (large woody debris. boulders). streams would not be able to recover to highly productive conditions. The variety of stream conditions mediated by natural disturbances is essential for maintaining biological diversity at the vvatershed level (Reice 1994) and may well be essential for supporting species such as Pacific salmon with complex metapopulation structure. To attempt to force streams toward a fixed set of conditions (e.g.. sediment concentrations. pool-riffle ratios. woody debris counts) using habitat standards and "improvement" technology runs counter to ecological processes responsible for maintaining long-term productivity.

Second. We should begin to plan for the eventuality of natural disturbances by making sure that when these events occur. the raw materials are in place for the disturbance to deliver them to streams. An example might be leaving trees in geologically unstable areas on hill-slopes. so that when landslides occur the trees are transported to the channel in a natural fashion. Another example might be to provide a wide buffer around a stream on a well-developed floodplain. so that the river can meander laterally and create overflow channels. This approach will require a landscape-level perspective of the watershed. with the focus being on identifying areas where aquatic-terrestrial interactions are most likely (Sedell et al. 1994). Such a perspective involves giving up some control over natural processes. but it will provide greater assurance of maintaining long-term productivity and biodiversity.

Salmon carcasses

Historical numbers of salmon spawning in lower Columbia tributaries are not known with certainty and probably varied considerably from year to year; however. it is very likely that many tributaries supported high densities of returning adults in the 19th century After spawning. the carcasses of salmon provided an important source of nutrients for terrestrial scavengers (Cederholm et al. 1989). Unspawned eggs, carcasses. and newly emerged fry likewise provided an important food source for various members of the aquatic community (Klein et al. 1990) and may also have contributed nutrients to riparian vegetation.

We are only now beginning to appreciate how important salmon carcasses are to the food web of aquatic ecosystems in the Pacific Northwest. Recent investigations (Bilby et al.. In press) suggest that certain nutrients (nitrogen and carbon) derived from carcass tissue are readily incorporated into the trophic pathways of streams and. through the process of bioaccumulation. can form a significant component of the tissue of juvenile salmonids: in other words. juvenile salmonids derive a significant food benefit from the carcasses of their parents and the carcasses of other species. The following table displays the percentage of marine-derived nitrogen and carbon. i.e., N and C from salmon carcasses. in the tissues of various trophic groups in Grizzly Creek, a small tributary of the Snoqualmie River that supports very large naturally spawning runs of coho salmon (> 500 adults per mile). These percentages were determined using the technique of stable isotope analysis, which permits marine-derived isotopes of nitrogen and carbon to be traced in tissue samples. While Grizzly Creek is not a lower Columbia tributary, it is one of the few low-gradient Puget Sound streams that still hosts high densities of wild coho salmon adults. As such it is a useful surrogate for the condition of many small streams in the lower Columbia in the 19th and early 20th centuries. As shown in the table, marine-derived nitrogen and carbon constitute approximately one fourth of the tissues of many aquatic-dwelling organisms. and for juvenile coho salmon the utilization of carcass nutrients is even higher.

Table 2
(R. E. Bilby. B. R. Fransen. and P. A. Bisson. unpublished. data)

	Percent of tissue derived from salmon carcasses	
	Nitroeen	Carbon
Riparian foliage	17.5	0
Epilithic organic matter	20.7	25.2
Invertebrate grazers	24.8	29.2
Invertebrate shredders	23.8	0
Collector-gatherers	14.4	29.4
Invertebrate predators	10.9	27.5
Age 0+ cutthroat trout	18.5	23.4
Age 1+, 2+ cutthroat trout	25.6	24.8
Age 0+ coho salmon	30.6	39.5

Over the last century there has been a marked reduction in the number of naturally-spawning salmon in the lower Columbia Basin (NRC 1995). Chief causes include habitat loss. high fishing rates. replacement of wild fish by hatchery fish. and natural cycles of ocean productivity. Given the high utilization of carcass tissue by fish and other stream-dwelling organisms. loss of salmon carcasses has probably had a significant impact on the carrying capacity for salmonids of lower Columbia tributaries. Unfortunately this loss is not easily quantified, but it is possible to estimate the total loss of carcass nutrients for the nearby Willapa Bay drainage system. an area very similar to the lower Columbia in many respects. The following table shows an order of magnitude reduction in carcass loading in Willapa Bay and its tributaries currently. relative to estimated adult returns earlier in this century (Suzumoto 1992. NRC 1995). Carcass biomass was assumed to be 0.364% phosphorus and 10.0% nitrogen by weight. The loss of 90% of the salmon returning to the basin's streams surely represents a significant impairment of the ability of the ecosystem to produce fish.

Table 3

	Delivery to streams (kg/km of stream length)		Delivery to Willapa Bay (kg/ha of surface area)	
	Historical	Recent	Historical	Recent
Phosphorus	3.0-5.0	0.3	0.23-0.31	0.02
Nitrogen	82-140	9.0	6.3-10.7	0.7
Total biomass	823-1400	86		

It is sometimes argued that allowing more salmon to return to spawn is not effective when habitat has been degraded. While it is certainly true that streams in the lower Columbia have been altered by human activity. efforts to restore ecological carrying capacity must be cognizant of biological as well as physical factors that control aquatic productivity. Attempting to rehabilitate physical habitat without considering such factors as salmon carcasses will not lead to full recovery of stream ecosystems. In formulating recovery plans for lower Columbia watersheds. consideration should be given to the complete spectrum of biophysical processes that influence carrying capacity. In all likelihood. recovery will be hastened by allowing adult escapement in excess of the number of fish needed to “fully seed” available habitat.

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**The carrying capacity concept
in fisheries management**

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The concept of carrying capacity has long played an important role in the study and management of plant and animal populations. The concept was recently reviewed by Pulliam & Haddad (1994) who trace the various definitions of carrying capacity and their application to human populations. Carrying capacity has been variously defined as (1) the maximum population of individuals attainable for a particular level of resources (e.g., food or nutrients), (2) the maximum population above which no increase will occur even if resource levels are increased (what Leopold [1933] terms the "saturation density" for a species). (3) a population threshold where all available cover has been saturated and mortality from predation increases rapidly, and (4) the upper limit where no population increase can occur as represented by the S-shaped (logistic) growth curve (Fig. 1). Although this last definition has appeared increasingly in the literature since its introduction by Odum in 1959, Pulliam & Haddad (1994) note that many more complicated patterns of population growth occur in natural systems. For example, many populations show more than one equilibrium level regulated by various limiting factors such as predation, disease, or social interactions (Fig. 2). Such factors may regulate populations well below the carrying capacity level set by available resources. Furthermore, multiple points of stability and instability in natural populations may themselves fluctuate as environmental conditions change (Pulliam & Haddad 1994).

In fisheries science, ideas about the carrying capacity of aquatic ecosystems are deeply rooted in the early agricultural purpose of fish management: to maximize production and assure an equitable distribution of fishery resources for the benefit of people (Bottom In Press). From the presumption of a world designed for human use, fisheries science sought evidence and developed theories to explain this design. Examples of these ideas include the assumption that natural fish populations achieve a stable equilibrium level set by available resources and defined by a logistic growth curve: the belief in a maximum sustainable yield (also based on the logistic growth curve) which can be forever harvested without adversely affecting a population or its ecosystem; the idea of single, independent "limiting factors" that constrain fish production and can be selectively removed to increase it; and, finally, the notion of surplus production in nature that is merely wasted if not claimed for human benefit. Examples of this "waste" are the vast supply of salmon eggs that perish while incubating in the gravel (and, therefore. wasted if not propagated in hatcheries) or the "excess" quantity of adult fish above the theoretical number needed to achieve the maximum production of recruits (and, therefore, wasted if not harvested in fisheries).

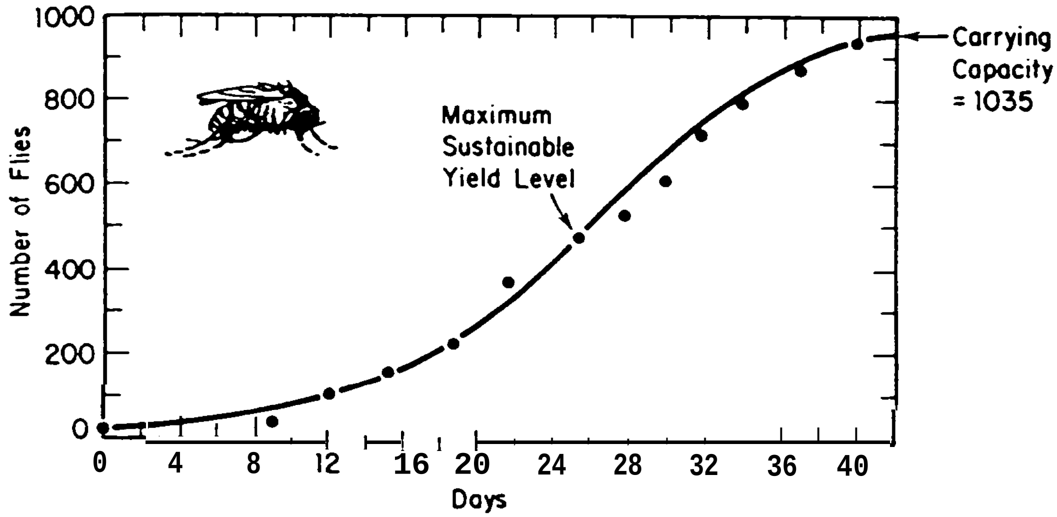

Figure 1
Logistic growth curve for a population of fruit flies held under constant temperature and environmental conditions (from Botkin 1990).

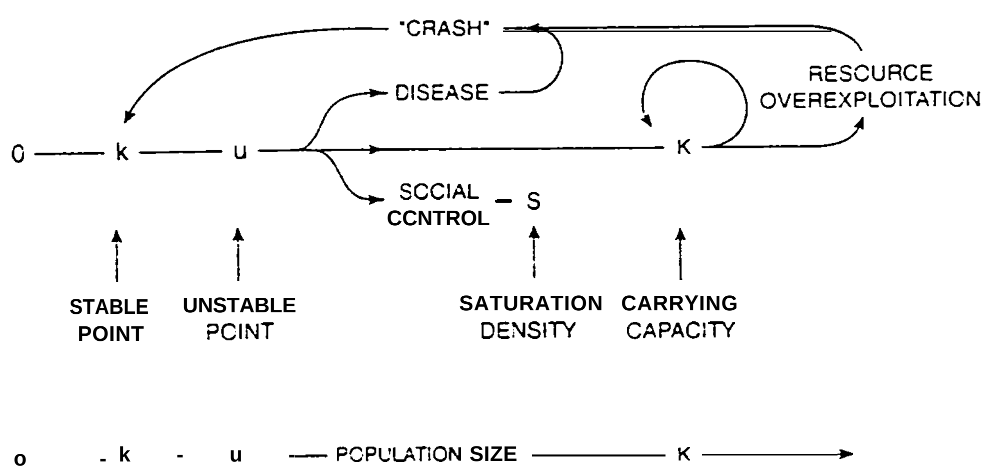

Figure 2
Examples of factors that may cause complex dynamics in natural populations. As the population increases, it may reach one of two stable levels. *k* is a population size set by predation. and *K* is set by available resources. Social control (e.g.. dominance hierarchies or defense of territories) may maintain a stable population below *K*. Over exploitation of resources or disease may cause the population to "crash" (from Pulliam & Haddad 1994). These results illustrate the potential inadequacy of a simple logistic growth curve to depict population growth and carrying capacity.

For much of the history of fish management, predation, competition, disease, and other interactions with target species were defined as limiting factors that prevent a population from achieving its potential productivity (carrying capacity). Management efforts emphasized the removal of these constraints through predator control, chemical treatment ("rehabilitation") of lakes and streams, habitat manipulations, and artificial propagation of valued species (Bottom In Press). Constraints to trout and salmon production were most often associated with high rates of mortality experienced during early life stages, which could be minimized by rearing fish in hatcheries. Yet once these constraints were removed, fisheries managers presumed little or no limit to the capacities of rivers, estuaries, or oceans to absorb whatever quantities of fish were released.

In the late 1970s, increasing concern for the conservation of wild salmon stocks and the establishment of large hatchery release-recapture facilities on Oregon estuaries momentarily shifted attention from the limiting factors in freshwater to the carrying capacity of estuaries. In Sixes River estuary, researchers found evidence of a growth limitation for wild chinook salmon. which occurred through a complex interaction between estuarine water temperature, prey production, behavioral and environmental controls on prey availability. and the number of fish entering the estuary (Figs. 3-4) (Reimers & Downey 1982, Nicholas et al. 1984, Nielson et al. 1985). They hypothesized that early ocean survival of salmon could decline in years when estuarine carrying capacity prevents significant numbers of smolts from reaching a threshold size (about 12 cm) before the fish migrate to sea.

Declining production of Oregon coho salmon in the late 1970s, despite steady increases in hatchery output. also raised concerns about limiting factors in the nearshore ocean environment (Fig. 5). Correlations between coho salmon survival and coastal upwelling suggested that annual fish production may be determined by marine conditions during the first few weeks or months after young salmon enter the ocean (Fig. 6) (Nickelson 1986). Recent studies now describe decadal or longer variations in ocean and atmospheric circulation across the entire Pacific Ocean Basin that may have an overriding influence on local environmental conditions and salmon productivity (Barber 1988, Beamish & Bouillon 1993).

These and other findings illustrate some of the basic flaws of a static concept of carrying capacity when applied to salmon in their natural environments:

(1) The diversity of salmon life histories within and among river basins violates the assumption that carrying capacity can be estimated for a uniform population with a single set of requirements and limitations. Furthermore, the factors that control salmon growth and survival interact in complex ways, negating the simple assumption of independent limiting factors controlled by the resource in shortest supply (e.g., Liebig's Law; see Cohen 1995). This is illustrated by the interactive effects of estuarine circulation processes. prey availability. and water temperature on the growth of juvenile chinook salmon (Figure 4) (Reimers & Downey 1982. Nicholas et al. 1984, Nielson et al. 1985).

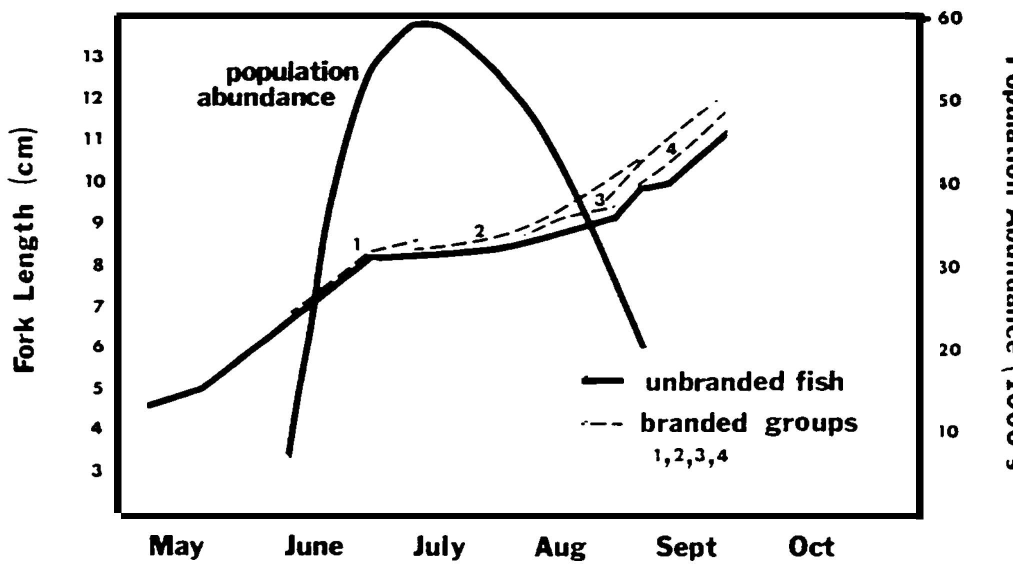

Figure 3
Abundance of juvenile chinook salmon in Sixes River estuary and their mean size in 1980. Salmon experienced a period of slow growth lasting approximately 7 weeks, while in 1979 no growth reduction was noted at approximately the same population densities. Annual differences in mean growth rate of salmon in the estuary are regulated by the density of fish. the production and availability of prey. and the energetic requirements of chinook as affected by variations in water temperature.

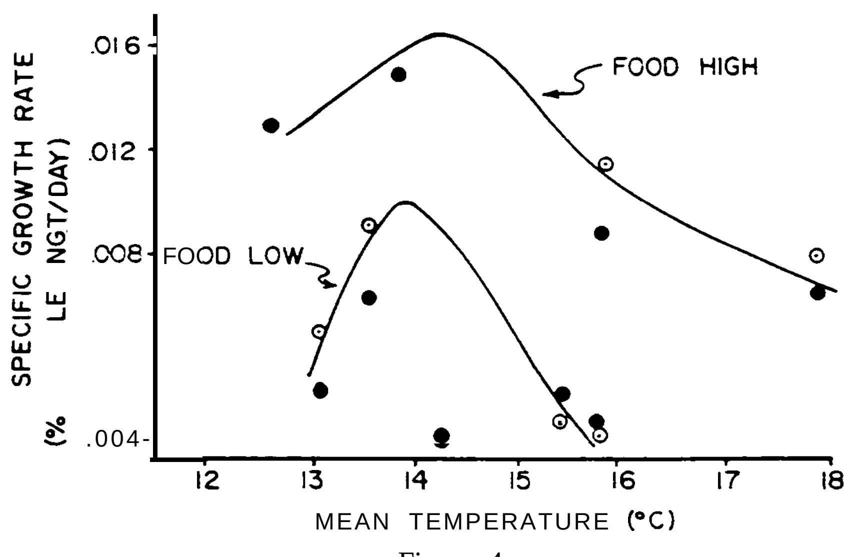

Figure 4
Variations in salmon growth rate in relation to temperature in Sises River estuary. June-September 1980. Hypothetical curves are drawn to depict the probable relationship between growth and temperature at high (June and September) and low (July through August) levels of estuarine food availability. Results suggest a decrease in the optimum temperature for growth when food levels decline. A similar interactive effect of ration size and temperature was demonstrated in laboratory esperiments on the growth of juvenile sockeye salmon (Brett et al. 1969).

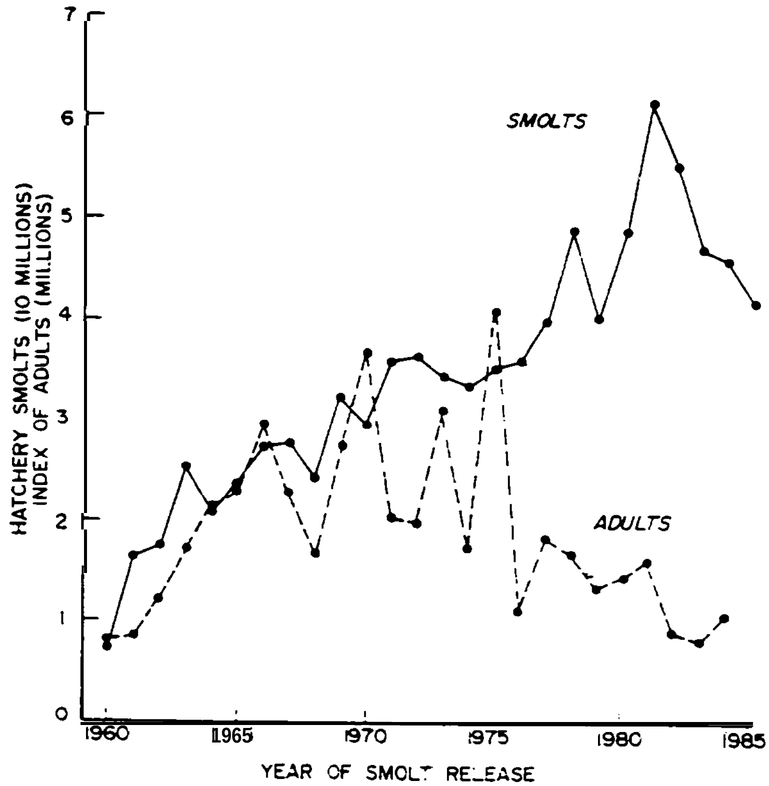

Figure 5

Numbers of hatchery coho salmon smolts released and the return of hatchery and wild adults the following year in the Oregon Production Area (from Nickelson 1986).

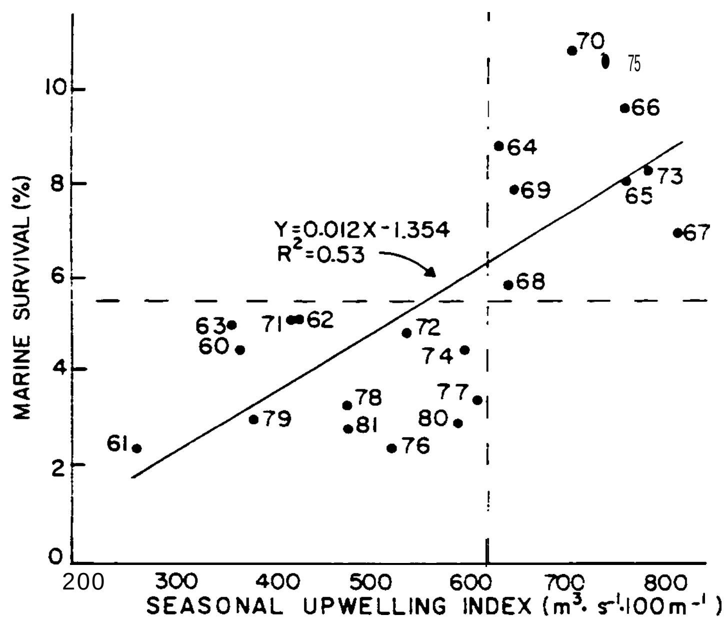

Figure 6

Correlation between percent survival of hatchery coho salmon smolts in the Oregon Production Area and a seasonal upwelling index calculated from the sum of monthly upwelling volumes, March-September at 42°N, 125°W (adapted from Nickelson 1986).

(2) The Pacific Ocean Basin does not move toward a stable condition but oscillates between alternate states. further violating the simple assumptions of constancy in population models. In fact. it is the pronounced *luck* of stability in marine ecosystems that triggers aperiodic pulses of biological production in different locales. For example, lack of uniformity in the global heat distribution causes seasonal changes in local wind fields, a spring shift in the direction of along-shore surface currents, and episodes of upwelling along the Oregon coast. These changes. in turn, disrupt a stable water column by raising cold. nutrient-rich water trapped deep below the thermocline and thereby enhancing primary and secondary production in coastal waters. At a larger scale, shifts in the strength and position of the Aleution low-pressure system over the central north Pacific Ocean may redirect the regional distribution of nutrients by changing the relative volumes of subarctic water transported northward into the Alaskan Gyre and southward into the California Current. Decadal and longer variations in salmon production off the Oregon and Washington coast may be attributed. in part. to these large-scale changes in ocean conditions (Fig. 7) (Francis 1993, Lichatowich 1993). In addition, because these same atmospheric oscillations alter the direction of storm tracks. they also regulate patterns of flow and temperature in streams. which, in turn, may affect freshwater survival of salmon (Greenland 1994). These large-scale shifts in climatic regime do not just change aquatic productivities; they also change the carrying capacity “rules” by altering the interrelationships among components of aquatic ecosystems, which determine how much of this production can be realized by salmon. Thus. for example, the predictive relationships between salmon survival and upwelling derived from observations under one climatic state (Figure 6) no longer seem to apply under the present regime.

(3) The limiting factors at different stages in the life cycle of salmon interact such that the carrying capacity of one ecosystem may not be under-stood in isolation from another. Through the migrations of salmon and the continual process of natural selection, the carrying capacities of freshwater. estuarine. and marine ecosystems become linked to one another in time and space. The performance (e.g., growth. mortality) of a population at one life stage and in one environment influences the subsequent performance of other life stages in new environments (Fig. 8). Furthermore. because the potential performance of salmon populations is molded by selective pressures — that is. the system "learns" (adapts) from its past — carrying capacity may change in the future even if environmental conditions do not.

(4) Traditional ideas about “surplus” and “waste” inferred from equilibrium population models are not very useful when applied to natural systems, which have evolved intricate pathways for the flow of energy. recycling of materials. and the damping of environmental variations. The quantities derived from equilibrium population models — maximum sustained yield or estimates of carrying capacity — say nothing about the functional role of fish in aquatic ecosystems. For example, estimates of the “harvestable surplus” available to fisheries do not consider the role of salmon in aquatic or terrestrial food chains or the possibility that the “excess” spawners removed by fisheries may regulate productivity by recycling oceanic carbon and nutrients back to

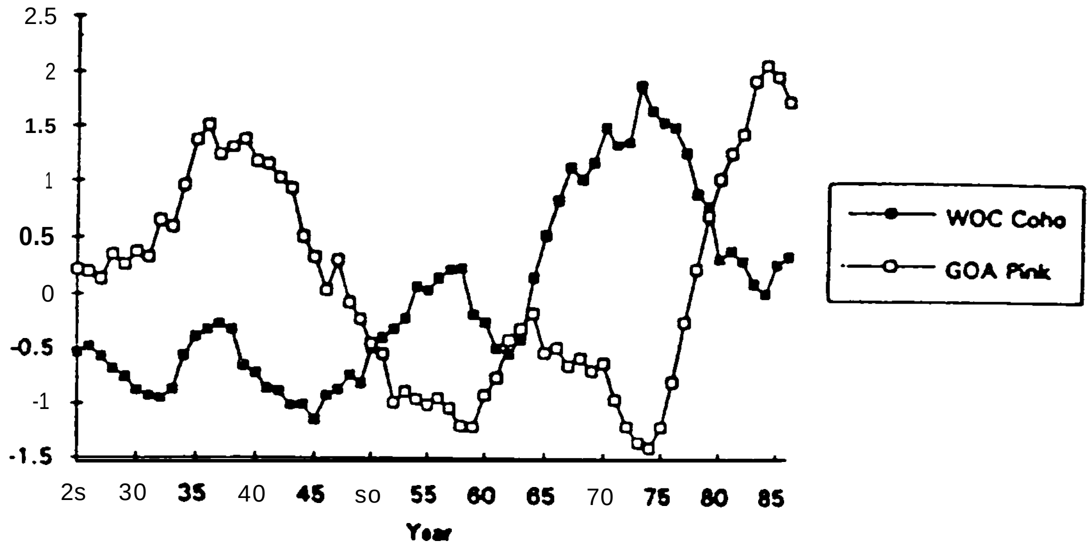

Figure 7
Comparison of normalized catches of Washington, Oregon, and California coho salmon and Gulf of Alaska pink salmon (from Francis & Sibley 1991). Contrasting cycles of abundance for central North Pacific vs. northeast Pacific salmon stocks may be related to the relative strength of flows in the California Current as affected by changes in the strength and position of the Aleution low-pressure system.

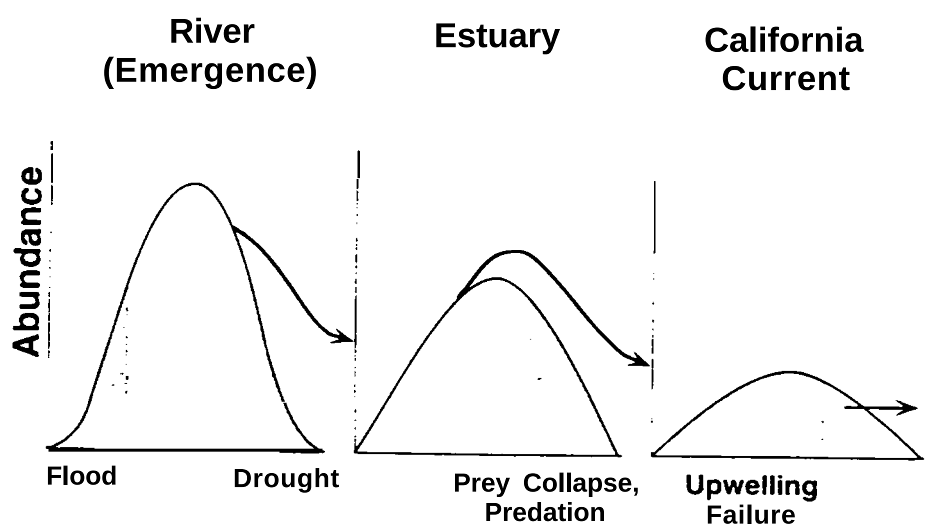

Figure 8
Hypothetical curves illustrating how selective pressures at each stage in the life cycle of salmon influence both the abundance and genetic character of a population during each subsequent stage. Thus. the carrying capacities of riverine. estuarine, and marine environments for salmon are linked in space (through the migrations of surviving salmon of a certain size and potential for continued survival) and in time (through the genetic "memory" of all past conditions that permitted survival to adult).

stream systems. Furthermore. harvesting the aggregate "surpluses" of individual target species ignores the combined effects of such harvest on fish assemblages and ecosystems. For example. Pauly & Christensen (1995) estimate that 24—35% of the primary production of freshwater. upwelling, and shelf ecosystems is required to maintain current levels of harvest in world fisheries (Fig. 9). Considering the large proportion of the total primary production that is lost as detritus and therefore unavailable to fish. these estimates suggest a substantial cumulative effect on aquatic food chains. Thus. the cumulative harvest of individual population "surpluses" raises serious concerns for biodiversity and the stability of entire ecosystems.

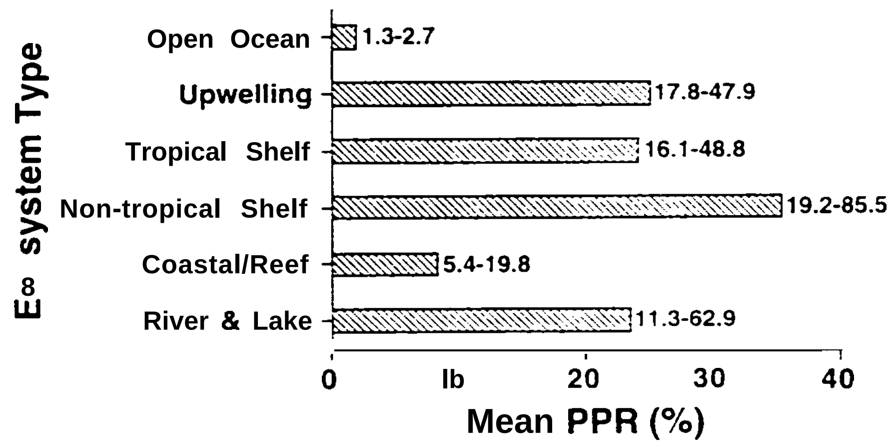

Figure 9

Global estimates of primary production required to sustain world fisheries (mean for 1988- 199 1) by ecosystem type (adapted from Pauly & Christensen 1995).

For all the above reasons. management manipulations intended to achieve or increase the theoretical carrying capacity for a species may. in fact. alter carrying capacity in unexpected ways. Often efforts to stabilize natural systems — for example. by damping natural disturbances. reducing biotic interactions. and artificially increasing production — paradoxically cause greater instability and reduce the carrying capacities of aquatic ecosystems for salmon. To the extent that carrying capacity is defined as an equilibrium population model we use to project our economic values onto nature. it is not very useful. The utility of the concept lies not in the quantities we estimate but in the questions we have to answer to understand what carrying capacity might possibly, mean. Resource managers need an alternative conceptual framework for understanding the linkages between aquatic ecosystems and salmon populations. Rather than simply seeking scientific justification for removing so-called "limiting factors." questions about carrying capacity should demand of us a better understanding of why living systems have become organized and patterned as they are. In this way. evaluations of carrying capacity should provide a means for adapting human behavior to those evolutionary constraints (e.g., interdependencies) that have allowed salmon and other native species to persist in a changing world.

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Lost ecological carrying capacity in the Columbia mainstem[4]

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I suggest that the Columbia River Basin has lost a major portion of its mainstem carrying capacity for juvenile salmonids, particularly under-yearling fall chinook salmon outmigrants. If we postulate that there is such a thing as carrying capacity, then we must look carefully at components of that capacity in the early historical river before the 1930s and compare them with the present altered (dammed and flow-regulated) condition (Lichatowich et al. 1995). Clearly, the habitats of the mainstem Snake and Columbia rivers differ considerably today from those that shaped the evolution of anadromous salmonids.

The pre-dam mainstem Columbia and Snake rivers were classic gravel-bed rivers, dominated by gravel and cobble (rounded rock) substratum variously constituted as bars, low islands, runs and pools with backchannels and sloughs. Riparian vegetation was typically restricted to a narrow shore-line zone in this arid region (Buss & Wing 1966, Hanson & Eberhardt 1971. Lewke & Buss 1977, Fickeisen et al. 1980a.b, Rickard et al. 1982). Different floral communities colonized shifting sands at the river's edge, alluvial fans at the mouths of tributary canyons. cobble and gravel slopes, outcroppings of basalt and granite, and disturbed areas caused by annual erosion, rock slides, grazing, and flooding that resulted in serial plant stages. In the entire main-stem, these features remain only in the Hanford Reach.

The salmonid life cycles were intimately linked to an annual flooding cycle of the mainstem. Fall chinook salmon fry emerging from gravel in spring began their feeding and rearing phase in shorelines and sloughs as mainstem water levels rose across cobble bars and into riparian vegetation with the melt of winter snowpacks in the tributaries. The most active rearing period for chinook underyearlings in the mainstem often occurred in late spring and early summer when waters were highest and the most riparian vegetation was flooded. The underyearlings moved gradually downstream through the summer, rearing as they went. Yearlings moved downstream relatively quickly during this same spring freshet period, but there is evidence that they, too, paused periodically in back eddies to feed (Schreck et al. 1994).

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Submerged riparian vegetation is important for young salmon as a substrate for production of invertebrate food. There is ample evidence that submerged plant material may be related generally to prey abundance and fish growth. Submerged wood is clearly an important habitat in other aquatic systems for growing invertebrates. especially aquatic insects of the Chironomidae (midges) (Nilsen & Larimore 1973. Benke et al. 1984. Stites & Benke 1989). Larger submerged surface areas generally translate to more invertebrates. as with submerged stream macrophytes (Gregg & Rose 1985). Coho salmon fry eat pupae and adults of chironomids as they drift downstream (Mundie 1969. 1971). Becker (1973) established that adult midges composed more than half of the diet of underyearling chinook salmon in the Hanford Reach of the Columbia River. Larval chironomids of all sizes are also a common component of stream drift (Mundie 1971. Oliver 1971) but are less commonly eaten by young salmon. Drift of chironomid larvae seems to serve largely to colonize the submerged surfaces. where the larvae feed on periphyton and attached organic silt and grow rapidly (Oliver 1971). Drifting chironomid larvae loosened from the streambed or as newly hatched instars quickly colonize previously exposed cobbles and submerged vegetation when waters rise. They develop within a few weeks to the pupae and emergent adults that are preferred food for young salmonids. Chironomids have their peak production in the spring at the time of peak abundance of juvenile salmon. The flooded riparian vegetation also provides terrestrial insects (e.g.. ants and spiders) as salmon food. Because underyearling salmon are at the edges of rivers and in back eddies (Mundie 1969. 1974). they are away from most of the drifting benthic (lotic) imvertebrates and in a zone where drift derived from overhanging brush and flooded riparian vegetation would be most valuable. The importance of flood pulses in riverine ecosystems in general is described by Power et al. (1988). Welcomme (1988). and Junk et al. (1989).

Hydroelectric development has both transformed riverine riparian areas into reservoirs (often with fairly stable water elevations) and reduced historical flood peaks that previously had inundated vegetated shoreline areas. Shorelines once fringed with vegetation are now lined with rock rip rap (U.S. Army Corps of Engineers 1976). which produces little insect life suitable as salmonid food (Janecek & Moog 1994). Slowly moving shoreline waters of reservoirs warm rapidly in summer, forcing juvenile salmon to move to the cooler channel (Curet 1993). The qualitative result is a system that does not appear capable of producing nearly as much high-quality food for juvenile salmon as did the free-flowing and annually flooding river. The success of fall chinook salmon in the still-riverine Hanford Reach, compared to the endangered status of this race in the fully dammed Snake River, is perhaps partly a result of the differences in food production. Whereas much attention has been given to timing of juvenile outmigrations to match food-production cycles in the estuary and ocean (Walters et al. 1978) little attention has been paid to correlations between timing of fish abundance. flooding of riparian habitats. and food-production cycles in the mainstem. Historically positive flow-survival relationships for salmon in the Columbia-Snake rivers may relate. at least in part. to the amount of riparian vegetation flooded and thus available as substrates for aquatic insect colonization.

Current knowledge specific to the Columbia and Snake rivers falls short of quantifying the benefit of flooded riparian vegetation in the ecology of juvenile salmon (still possible at Hanford) or its loss through most of the mainstem. Such knowledge would, however, be useful for the contemporary problem of rehabilitating the carrying capacity of salmon rearing habitats. I propose that the importance of riparian habitat for invertebrate (especially Chironomid) food production be a working hypothesis for studies of carrying capacity in the Columbia River Basin mainstem rivers. Useful comparisons could be made between Hanford and various reservoir reaches to quantify, as best we can today, the losses through impoundment. If the hypothesized benefits are substantiated and high, then proposals for flow augmentation and reservoir drawdowns could logically take into consideration a restoration of more natural shoreline vegetation and its seasonal flooding.

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Measuring salmonid carrying capacity of the Columbia River estuary

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Carrying capacity has been defined by many authors in terrestrial and aquatic systems (Bennett 1970, Lackey & Nielsen 1980, Leopold 1961, Miller 1993). Central to these definitions has been the concept of a maximal population or biomass that can be supported over a period of time, given limitations of physical and biological factors. These physical (e.g., temperature, dissolved oxygen, salinity) and biological (e.g., prey availability, predation, competition) factors vary in space and time (Goyke & Brandt 1993; Sprules & Jin 1990, Luo & Brandt 1993) and, thus. must be considered in evaluating carrying capacity or habitat quality for a given species. We adapt the “scope for growth” concept for operationally defining habitat quality as applied to individual species (Constanza 1992). Scope for growth is simply the difference between energy allocated to maintenance and activity and energy allocated to growth or reproduction (Mason et al. 1995).

Here we present the concept of growth-rate potential (GRP) as a measure of carrying capacity for salmonids in the Columbia River Estuary. Growth-rate potential is the expected growth of a predator if placed within a given volume of water under known biological or physical conditions (Fig. 1). Thus, GRP reflects the individual’s response to environmental conditions, metabolic requirements, and prey availability. As such, GRP reflects the quality of habitat, with maximum growth rate indicating highest habitat quality. High growth rates in fish are believed to improve sunvivorship, may be responsible for good year-classes, and allow individuals to attain larger size at age (Houde 1987, Pepin & Meyers 1991). Furthermore, the largest females in a population often produce larger and more viable eggs that may enhance survival of young (Zastrow et al. 1989, Monteleone & Houde 1990). Thus, growth rate is an indicator of an individual’s well being and provides a link between individual, population, and evolutionary fitness.

In large estuarine ecosystems, zooplankton and prey fish distributions are typically not homogeneous, with physical environment also varying both spatially and temporally. We apply a grid framework incorporating the spatial complexities of the physical and biological environment. along with the energetics of the species in question. to arrive at a measure of habitat quality. Size of the spatial cells are dictated by the spatial distribution of prey and the thermal environment. A foraging model and physiological growth model are then run in each cell of the grid to calculate GRP if a fish were placed in that particular cell. Inputs to the model include temperature, salinity, and dissolved oxygen concentration along with prey density and prey size. Out of the model is growth. We present specific examples for species in the Chesapeake Bay that clearly indicate that habitat quality changes with season, size-class of predator, and species of predator (Figs. 2-4).

To implement this approach for the Columbia system, spatial data on the biological and physical conditions of the environment are needed. specifically prey density. prey size. water temperature, salinity. and dissolved oxygen. We have used hydroacoustic techniques to evaluate prey fish biomass, size, and distribution for inputs of prey availability in Chesapeake Bay. Similar techniques should provide reliable measures for prey of piscivorous salmonids in the Columbia. However, planktivorous salmonid prey field measurement would require alternate approaches. such as optical plankton counters. Much of the additional information required to implement a measure of GRP for the Columbia River Estuary already exists. Bioenergetics models have been developed for common salmonids such as chinook salmon (Stewart & Ibarra 1991) and sockeye salmon (Beauchamp et al. 1989). Other potential adaptations of the modeling approach are to include additional dimensions that incorporate predation risk and competition.

The spatially explicit approach provides a framework for evaluating species-specific habitat needs based on physiological requirements of fish. This approach integrates information of the physiological response of fish that could not be determined by independent measures of physical or biological factors.

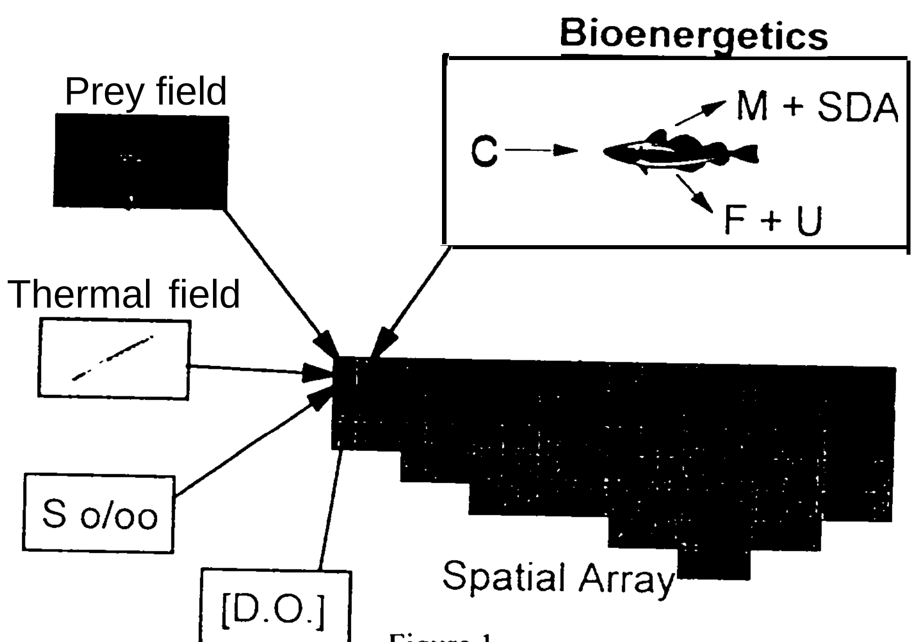

Figure 1

Basis of spatial grid framework for spatially explicit models of fish growth-rate potential. The following are in like units (e.g.. g/g d-l): C = consumption rate; M = metabolism; SDA= specific dynamic action. or the heat lost through processing of food; F = egestion; U = excretion.

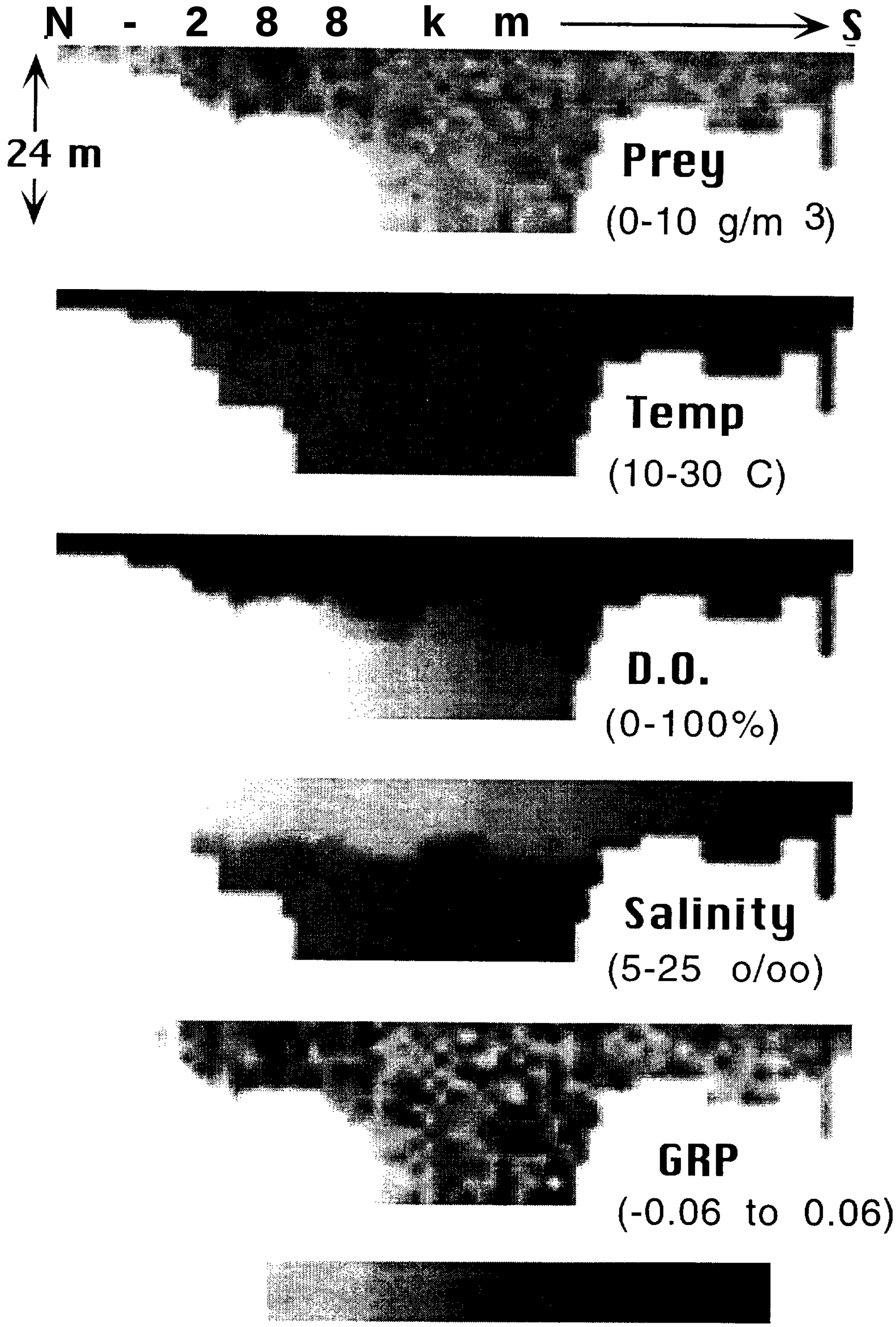

Figure 2

Spatially explicit model of fish growth-rate potential (GRP) for a 5-g weakfish *(Cynoscion regalis)* in Chesapeake Bay. Approximate cell size is 2-m depth by 2-km horizontal distance (from Hartman & Luo, in prep.).

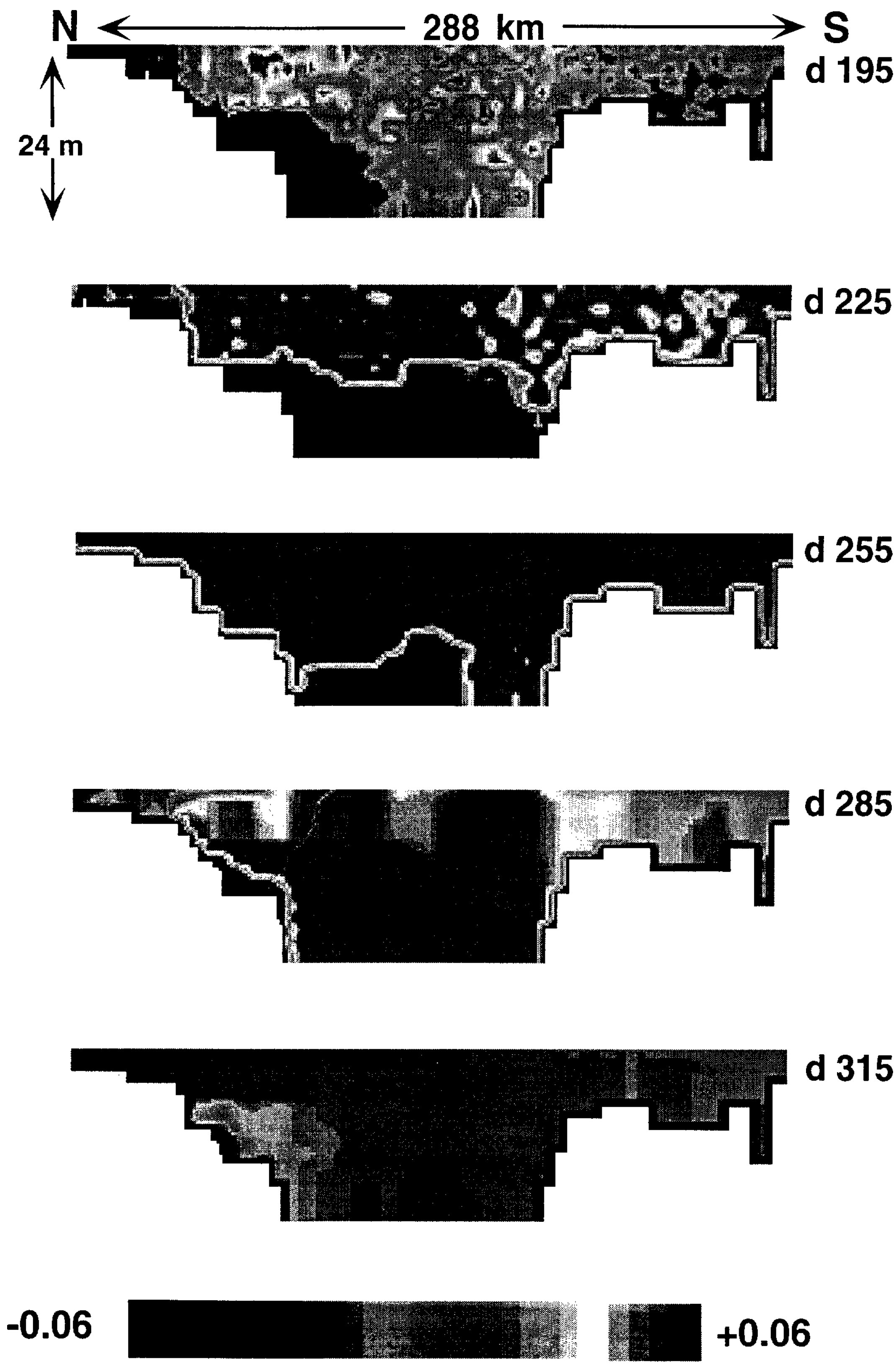

Figure 3
Seasonal changes in growth-rate potential (GRP) for a 5-g weakfish in Chesapeake Bay.

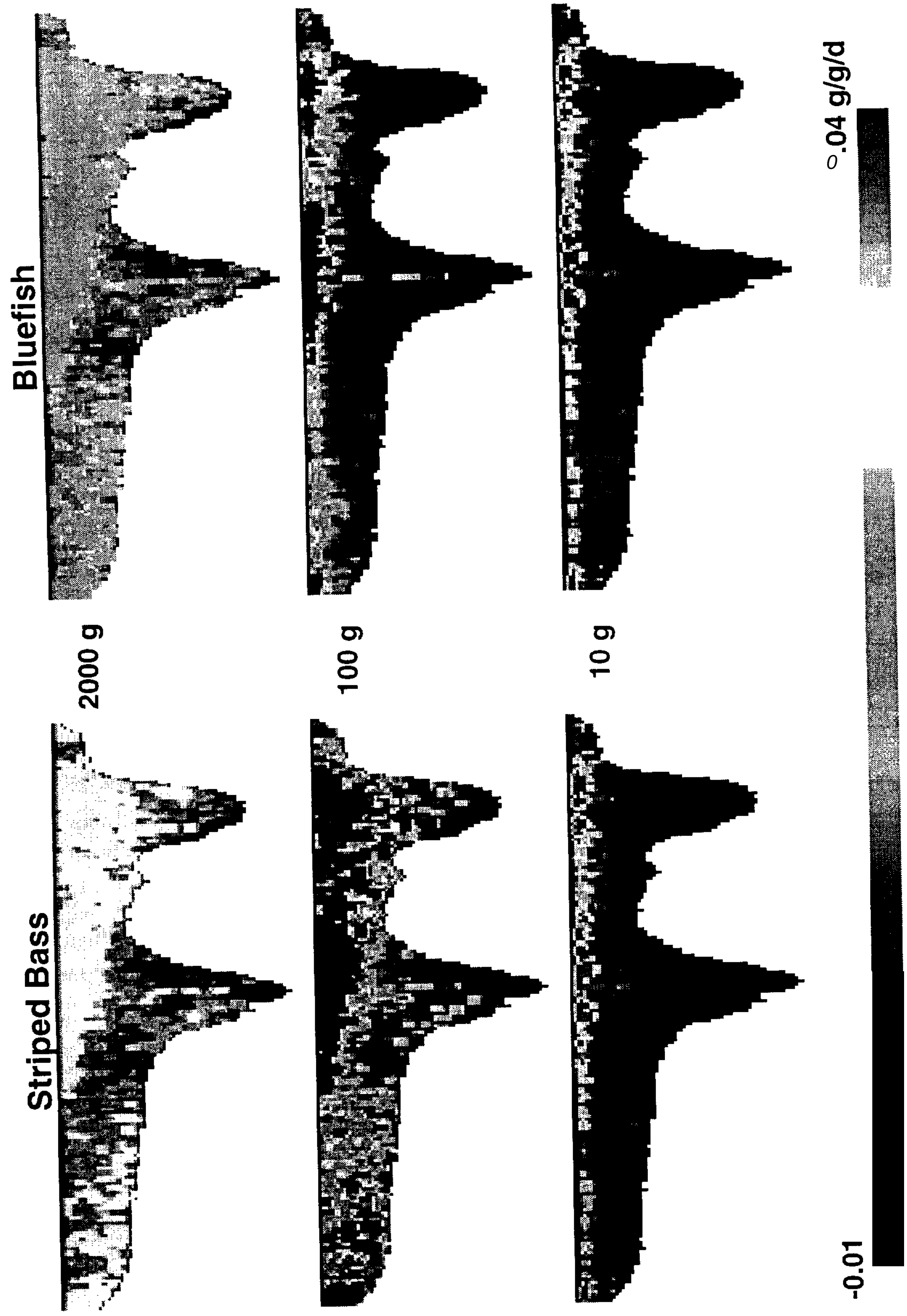

Figure 4

Species-specific differences in growth-rate potential (GRP) of striped bass *(Morone saxatilis)* and bluefish *(Pomatomus saltatrix)* during fall 1991 in Chesapeake Bay. Cell sizes are 0.5-m depth by 30-m horizontal distance (from Hartman et al., in review). Note significant differences in GRP between 100-g striped bass and bluefish.

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Stream carrying capacity and smolt production

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In thinking about carrying capacity of freshwater habitats of the Columbia River, I will begin by estimating the historic production of smolts. Information on estimated run sizes of salmon species available in the Power Council's "goals and losses" report (NPPC 1986) is shown here (Fig. 1). The historic estimated numbers of adults that were in the Columbia system above and below Bonneville Dam are shown separately. I have added some average fecundity figures for adults of the size-classes that we now have, and based on some fairly conservative egg-to-smolt survival rates, I calculated the number of smolts above and below Bonneville that may have been produced historically. The total for the entire system is about 1.4 billion smolts. Currently, total hatchery production ranges from 150 million to 190 million, and natural production is about 20% of the total. So you see that we don't have many smolts coming down the system anymore compared to what we may have had. Actually, the historic production is probably much more than this. I think these figures are conservative.

In the Columbia River Basin, habitat quantity has been severely reduced. Impassable dams block more than 55% of historical mainstem and tributary streams for anadromous fish (NPPC 1986). For remaining accessible stream miles, habitat quality has also been greatly reduced in most subbasins of the Basin. Quality and quantity are intimately linked. If quality of a habitat patch is reduced to 0%, quantity is essentially 0 in this patch. Therefore, habitat degradation in spawning gravel, for example, by addition of fine sediment, can reduce available spawning area and also reduce quality of remaining spawning gravel patches.

Reduction in quality of spawning habitat reduces survival-to-emergence (STE). This acts as a density-independent limitation to fry production, given a certain egg deposition. Density-independent processes act to <u>limit</u> the population to a level below its maximum attainable size that would have been reached in the absence of these processes. Density-dependent processes, such as competition for food and space, act to <u>regulate</u> the population size to a certain maximum level (McFadden 1969). Given a certain spawning escapement, potential egg deposition is dictated by fecundity, numbers, and proportion of females. If overall habitat quality is reduced to the point that stock productivity is very low (i.e., ≤ 2 adults return for every spawning pair; recruit to spawner ratio is <1.0) and carrying capacity is low, further reduction in quality of spawning gravel, for example, will result in a reduction in STE. This means that smolt yield will likely decline and fewer adults will return, other factors being equal. Although density-dependent mechanisms may in theory result in a somewhat greater survival at lower fry densities, it is unlikely that the effect would be strong enough to overcome the effect of habitat degradation. In addition, an increase in fine sediment in spawning gravel would probably be accompanied by an increase in cobble embeddedness, reducing carrying capacity for summer and winter rearing. Stream channel sedimentation can also reduce carrying capacity via its linkages to other key habitat factors.

That brings up the issue of carrying capacity. Why has it changed? I came up with a set of definitions (Fig. 2) from some pertinent literature. Burns (1971) said that "carrying capacity is defined as the greatest weight of fish that a stream can naturally support during the period of least available habitat. The stream's carrying capacity limits the number and weight of salmonid smolts ultimately produced." And,"production" (Figure 2) can be defined as "the quantity of fish material-this is from Allen (1969)-formed in the population during a given time, whether or not the fish survived till the end of the period." That's the classic definition of "production." Production is calculated as P = (G X mean B) for each size-class (Warren 1971). Any actions that reduce biomass or numbers (i.e., survival) or growth rate will affect production. But you can also consider the production potential as the ability to produce a certain smolt yield. So, in effect, consideration of carrying capacity involves ideas about numbers, growth, reproduction, immigration, emigration, and mortality. In an interesting critique of ecology, Peters (1991) says that "carrying capacity" is a very widely used term in ecology, but really it's the basis for an untestable theory. When our models describe the data well and we get nicely shaped curves, we like the theory. If the data do not conform to our models, we don't worry about that either, because we like the term. It's conceptually satisfying. And we don't challenge our theories, really, with data that are contrary.

Nonetheless, I think everyone agrees that there is such a thing as carrying capacity and the ability of any system, whether it's a lake or a stream, to produce fish. In this example (Fig. 3) from Charles Warren's (1971) book, he shows production curves for three sockeye salmon lakes. Lake Dalnee is a very productive lake, and lakes Babine-Nilkitkwa and Owikeno are very unproductive. There's a corresponding major difference in growth rates of the fish. And with that combination of growth rate and the biomass that is supportable, you get production curves that are shaped like this and vary considerably. Overlaying that with information from Burgner (199 l), I show the spawners per hectare that are supported in each of these systems (Fig. 4). Thus, Lake Dalnee can support 169 spawners/ha, the other two lakes, 13 to 45. The reasons for that, of course, involve the nutrients that are available in those systems, among other factors. And you have the same situation in streams. Streams vary in their production capacity because of nutrients and hydrologic regime, topographic features that set the basic framework for production, and other inherent characteristics of the watersheds. And then within that context, you have variations due to the way the systems are managed, such as canopy cover in the riparian zone. This separation of characteristics of natural systems (e.g., watersheds, streams, riparian zones, etc.) into capacities and performances is part of a theoretical framework developed by Warren (1979) that I will employ in this talk. Capacities can be partially typified by certain characteristics that are very stable and resistant to change and are very influential in determining the full range of performances that are possible for a system interacting with all possible states of its environment.

Performances are the responses of components of a natural system to environmental conditions and to the state of other system components.

Curves (Fig. 5) showing smolt densities versus egg deposition were produced by Symons (1979) in a study on Atlantic salmon. He gathered available information on survival and growth rates in a number of streams to produce these curves. Here (with 2+ age smolts) you can see a difference in carrying capacity in the streams he was looking at. Because some streams may have been somewhat degraded, their carrying capacity may have been reduced relative to what he estimates as the maximum for streams of that type in New England. The ability to produce smolts varies with the age of the smolts because of overwinter survival factors and also with annual habitat quality.

In estimating how carrying capacity has changed, we have to look at the quantity and quality of habitat. This picture of the Columbia Basin indicates some things about changes in habitat quantity (Fig. 6). The lightly shaded area represents drainages that never were accessible to salmon; the darkly shaded region was formerly productive salmon habitat but represents production lost due to impassable dams. Current anadromous fish carrying capacity depends upon the unshaded drainages. I should really have had a slide that shows a loss (reduction in production potential or increase in mortality rate) caused by passable dams. But, of course, you all are familiar with that story. For sockeye we've had a major loss in available spawning and rearing areas over the course of Columbia River development. In terms of total sockeye production from the Columbia Basin, carrying capacity has been reduced by removal of spawning and rearing area from production by creation of impassable barriers and deliberate eradication of sockeye from lakes (Fig. 7, CRITFC 1995). The spatial interrelationships between lakes that support sockeye are also a critical feature. It's definitely advantageous to have a number of lakes in an area that are producing sockeye rather than just one, so that there's a little hedging of bets there.

In any discussion of carrying capacity, you have to consider the habitat factors affecting survival and production; for example, temperature and the biologic requirements of the fish at various points in their life cycle. The literature on temperature requirements of spring chinook is summarized in Fig. 8. There are thresholds at 15.5°C above which the diseases of fish increase dramatically. Fish cannot spawn effectively above 16°C, and adult migration blockages are very common above 21 °C. For the rearing phases, as Chuck Coutant showed, growth becomes zero above about 19°C; actually it becomes increasingly negative. So this establishes an optimum range for growth. If streams are not currently providing these features through their life cycle, the production is going to be impaired. As I stated in the definition, anything that changes the numbers or biomass of fish during these stages will limit the carrying capacity and also the survival rates.

I think in many ways it's not really that critical to determine exactly what carrying capacity is. The search for limiting factors (a topic related to carrying capacity) is, I think, a misguided notion. I think we need to address all the factors that are responsibIe at all the fish's life stages. We often spend a lot of time debating what the most limiting factor is, but many of these critical habitat variables can be readjusted to near-historic levels by some fairly simple management prescriptions. For example, restoring riparian areas does a myriad of good things, partially reducing sediment loads in a watershed context and also limiting light to the stream, which reduces temperatures, expanding the available rearing area in the stream.

We have many, many large dams that create migration barriers for adult salmon and, in addition, reduce survival on downstream migration through the Columbia to the estuary. Approximately 90-98% of the smolts that pass through the entire system of dams are killed. On migration upstream, cumulative moralities are also very high, about 5-15% per dam. Data from Hatch et al. (1993) (Fig. 9) show migration blockages of sockeye moving up into Lake Osoyoos through Zosel Dam. This indicates that when the water temperature drops below the critical value of 70°F, migration peaks occur, and the fish are prevented from migrating when temperatures are higher. As long as temperatures are maintained too high for migration, a number of fish are not going to reach the spawning grounds on time, and thus a reduction in egg deposition and subsequent production is likely. Contrast this with the 70°F migration threshold for chinook and the Lower Granite Reservoir temperatures during the migration period (Karr et al. 1992) (Fig. 10). A significant period exists during which adult migration impairment can occur in the Snake River for both summer and fall runs, as well as mortality due to increased disease susceptibility and direct thermal effects.

There are several ways to predict fish yield from various systems (Fig. 11). In lakes you can use a morphoedaphic index, basically a function of total dissolved solids and mean depth. There are differences among lakes that affect carrying capacity. Some are very deep, some have lots of littoral areas where you can produce fish. That's a nice way to compare among lakes. Same thing for large floodplain rivers; for example, looking at rivers in Africa, the total annual yield of fish has to do with the ratio of low-water to high-water areas. Basically floodplain development affects the ability of fish to move out and use floodplain areas. Relationships developed by Welcomme (1976) and Welcomme & Hagborg (1977) are interesting for comparing rivers. But within the Columbia, we have only one river to deal with; we are stuck with whatever floodplain area exists — although, perhaps not necessarily. If we can restore it, like Chuck Coutant mentioned, that would help. The most effective means of restoring floodplain function is to restore the natural flow regime in the Columbia mainstem. The regulated flows that currently exist limit the use of floodplain area in the Columbia River during May-July and also do not provide sufficient juvenile outmigration flows (Fig. 12, CRITFC 1995).

For small streams, Fausch et al. (1988) reviewed about 99 papers that predicted standing crop as a function of habitat variables, a great number of variables. The major categories of variables from Fausch et al.? work, including a few examples of each, are presented in Fig. 13. This review illustrates that models developed for one locale can appear satisfying, but may or may not work when applied to another location. In many of these models, some very ecologically important variables are not even considered because they cannot be shown to explain the variance in a regression. For example, nutrients are frequently not considered, despite the fact that this variable establishes major differences between streams. And even maximum temperatures in the summer are often excluded. But these are key features that must be incorporated in more universal models of carrying capacity or fish production and survival.

You can look at control on carrying capacity at various hierarchical levels (Fig. 14). At a drainage basin level, Zeimer (1973) showed the influence of basin geomorphology on potential salmon production. At the stream network level, Murphy et al. (1986), Thedinga & Koski (1984) and Dolloff (1987) showed the importance of spatial connections between summer-rearing and winter-rearing areas. If a summer-rearing area has been clear-cut and large woody debris removed, there's a very limited potential there for overwinter rearing. So the fish have to move. If they can't find over-winter rearing, their survival will decrease. Dolloff actually recommends that high-quality riparian areas be maintained in all stream reaches where juvenile salmon summer-rear.

At a stream segment level, riffle/pool ratio is an important determinant of carrying capacity. Some data from Bisson (as cited by Sullivan et al. 1987) (Fig. 15) reflect at the riffle/pool level of habitat organization how species community organization is determined by changes in riffle/pool ratios that are often mediated by logging. In the stream that is dominated by pool channel units, there is a predominance of coho, steelhead, and cutthroat. The coho are eliminated as the pools are eliminated and the stream becomes dominated by riffles. The stream having a predominance of riffles is dominated by steelhead.

And at the channel unit level, there are various features of importance to salmonids: fine sediment, embeddedness, temperature, woody debris, pool volume, water flow (Fig. 14). I want to emphasize them all, because they provide significant site-specific and aggregated stream system-level controls on survival.

We can show survival during the pre-spawning, egg-to-fry, fry-to-pair, and parr-to-smolt stages as a function of various habitat variables, and look at all of these sequentially (Fig. 16). Temperature, I think, is one of the most significant keys to survival and carrying capacity across the Columbia Basin. The majority of the sub-basins have tributaries that are very elevated in water temperature. The data from Theurer et al. (1985) on the Tucannon River (Fig. 17) is very interesting; the solid line shows the current increase in water temperature on the mainstem from the headwaters downstream to the mouth. From river km 40 to the mouth, the mean daily July temperature is above the critical 20°C value. There are no juvenile salmon downstream of that point. They estimated, using the Fish and Wildlife Service temperature model, that if the channel morphology and riparian zone were restored, you could get a temperature reduction in the mainstem to below 20°C (as indicated by the dashed line), even down to the mouth that would open up a huge rearing area on this large-width stream to salmon production.

I went a little further here and made some theoretical estimates concerning spatial distribution of survival, growth, and biomass that reflect basically what Theurer et al. (1985) illustrated in their paper, i.e., an increase in production along with temperature improvement (a cooling trend). In terms of juvenile chinook survival, given the existing conditions, survival is expected to decrease to zero (Fig. 18) at river km 40. That critical temperature threshold (mean daily temperature of 20°C; maximum daily temperature of 23°C) has been shown in numerous studies to be one that causes chinook either to die or to leave. Chinook are generally not found in water temperatures above that, unless coldwater refuges are associated with the stream segment or channel unit. Potential survival rates probably drop to near zero at the mouth under restored conditions; but, still, there would be a much greater potential survival in the lower 40 km of the mainstem than under existing conditions.

A similar thing occurs in terms of growth rate (Fig. 19). Juvenile chinook can maintain positive growth rates at temperatures lower than the critical 19°C. They reach a growth rate of zero at 19°C. But through this lower large river reach under restored conditions, chinook can achieve positive growth rates. The current condition is for negative growth downstream of river km 40+. The headwaters in the Tucannon are a wilderness area, and under current management are not subject to harvest; however, there would be a potential increase in growth rate in the headwaters if riparian logging occurred and stream temperatures began to increase. But, really, the gradient is too steep from river km 80 to the upper end of the watershed. There is no potential for producing the rearing fish there, anyway, so there is really no benefit to increasing potential growth rates in the headwaters. And the downside is that in wide, downstream river reaches, you further restrict the growth rate so that there is even more unusable habitat. And when you look at biomass (Fig. 20), I think the same kind of relationship would hold. There is no biomass in the headwaters because of the steep channel gradient. There would likely be a small increase in the warmed, moderate gradient reaches where chinook are found at the upstream end of their distribution, but the total biomass from the entire stream system would be reduced as stream temperatures are increased starting from the headwaters.

Carrying capacity is determined by the combined effects of the characteristics of the region, the watershed, and stream and also by the habitat quantities and qualities, some of which have been described (see Figures 14 and 16). Water temperature is a significant habitat factor con-trolling carrying capacity. It is governed by the capacities (capabilities) of the hierarchical units of the land-water system that provide the entire fish habitat system (Fig. 21). Singling out temperature, the long-term temperature regime is framed by many stable characteristics of the land-water system at various levels in the hierarchy, such as regional climate, latitude, elevation of the stream, potential riparian community, channel width, and flow volume. Current temperature performances can be specified in relation to natural- and management-related impacts. Removal of riparian cover alters the short-term temperature regime within the context of its long-term capability, This theoretical framework allows one to expect a capability for similar temperature regimes in streams of similar type. Given similar capabilities in temperature regime, the performances could vary due to recent management influence or a series of natural events in the riparian zone. Li et al. (1992) developed some interesting data on the effect of temperature on the coldwater fish (primarily steelhead) of the John Day River (Fig. 22). These data indicate a reduction in trout biomass as mean daily water temperatures increase from about 12° to 22°C. Juvenile fish densities reach zero when mean daily temperature approaches approximately 22°C.

The preceding discussion has dealt with effects of water temperature on chinook survival, growth, and biomass. In terms of the effects of fine sediment on juvenile chinook, data from the Forest Service (USDA Forest Service 1981, 1983) indicate a negative relationship between fine sediment and survival (Fig. 23). When fine sediment in spawning gravel increases beyond 20%, egg-to-fry survival starts to precipitously decline. Scully & Petrosky (1991) found that when mean surface fine sediment is ~30% in tributaries of the Middle Fork of the Salmon River, egg-to-parr survival is much greater than in tributaries having greater amounts (Fig. 24). In terms of density of rearing fish, the Bear Valley/Elk Creek systems of the Middle Fork Salmon River, Idaho, which have elevated fine sediment levels from past mining, logging, and grazing have very low rearing densities (Fig. 25). In the control streams for that same area, there are much higher densities of fish.

Summer carrying capacity declines with increasing cobble embeddedness (USDA Forest Service 1983; Fig. 26). As embeddedness increases, there is less capacity in a rearing area for the fish to seek shelter or for them to have visual separation in dividing up the available habitat. Winter carrying capacity is largely dependent on pool availability and cobble embeddedness, both influenced by fine sediment delivery. The loss of pools that has been widespread across the Basin reduces the capacity to rear juveniles during the winter. If streams are managed so that embeddedness remains below 30%, the ability to support juvenile chinook is higher in comparison to densities supportable when embeddedness is greater than 30% (Fig. 27).

Murphy et al. (1986) (as cited by Bisson et al. 1987) show that retaining large woody debris in the stream can effectively increase the potential to support coho parr (Fig. 28). Sedell & Everest (1990), McIntosh 1992, and McIntosh et al. 1994 (Fig. 29) revealed that there has been a huge loss in the frequency of large pools in streams throughout the Columbia River system since 1935. These pools are essential for adult spring and summer chinook pre-spawning holding. Elimination of large woody debris and/or fine sediment delivery to stream channels are largely responsible for loss of these pools. Reduction in pool frequency is a major capacity limitation to the system for the Grande Ronde, the Salmon, and Clearwater rivers — a loss of 35-65%, depending upon the river.

In effect, I think carrying capacity is an interesting topic academically. Ecologists find it to be a challenging one to try to come to grips with. But I think in terms of management, we know the means to control salmon numbers, biomass, and survival. In many ways, survival and capacity really are intertwined. Increase in fine sediment will eliminate pool volume, which eliminates capacity and, at the same time, reduces survival.

Fine sediment infiltrates into spawning gravel and causes density-independent mortality during the incubation period, effectively reducing the capacity of the stream to produce emergent fry. Regardless of how many eggs are deposited in the gravel, if fine sediment levels are high, high mortality will ensue in the emergence stage and in later life stages. So, if we can address critical habitat features — sediment, temperature, pool volumes, large woody debris — through effective management of the riparian areas, restoration of riparian zones, and gaining control over sediment production at the watershed scale, salmon survival and production should improve. In essence, concern about estimating carrying capacity before proceeding with needed restorative actions becomes irrelevant. We know we are proceeding in the right direction if we can achieve improvement in key habitat features that are intimately linked with high survival and production of salmon. Many of these inter-related habitat variables are influenced by a limited set of management actions that can be addressed routinely by land managers (e.g., full protection of riparian zone). Reliance on limiting-factor or carrying-capacity analysis serves merely as a means to justify disaggregating an integrated natural system so that symptoms (e.g., lack of woody debris) can be treated out of context with the whole system.

MS. BERWICK: I didn’t see pollutants or contaminants on the list of factors that you were suggesting determine carrying capacity.

MR. MCCULLOUGH: Yes. That’s a definite concern. We have been concerned about the transport of toxic chemicals, as in the Snake River Basin, cyanide from mining, transport of diesel fuel, and things like that. And in a number of cases, it does cause large moralities. There have been spills in the John Day and Salmon River basins, and elsewhere. And, yes, the number of additional mines that are coming on-line or are potentially in the works can change the pH of water. And where you have heavy metals that pollute the stream or pH changes, the carrying capacity can be reduced to zero for salmon for a considerable distance downstream.

But it seems to me that except for urban areas, the majority of headwater streams and major tributaries to the Columbia River are limited by the temperature, sediment, loss of structure in the stream, loss of woody debris, pools, etc., more than by chemical pollutants. But it is true that along large tributaries and the mainstem Columbia River, a few additional concerns have been raised. Some of the agricultural pesticides have some scary implications because they can produce estrogenic effects that can cause reproductive anomalies in the males, such as development of female traits. And, if that’s a sustained source of perturbation to a watershed, that would be an impairment to carrying capacity as long as it’s occurring. And there’s probably little you could do in habitat restoration that would reverse that. Release of dioxin into the mainstem Columbia River has also become a special source of concern to northwest Native American tribes because of the bioconcentration in fish tissue.

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Predevelopment Run Size Above Bonneville

SPECIES	NO. ADULTS	FECUNDITY	EGG-TO-SMOLT SURVIVAL	NO. SMOLTS
Spring chlnook	1,909,000	4500	0.015	64,428,750
Summer chinook	4,600,000	5000	0.015	172,500,000
Fall chlnook	1,219,000	5500	0.050	167,612,500
Sockeye	2,600,000	2500	0.040	130,000,000
Coho	854,000	2500	0.010	1,0675,000
Chum		2500	0.350	0
Summer steelhead	1,105,000	3500	0.010	1,9337,500
TOTAL	12,287,000			56,4553,750

Predevelopment Run Size Below Bonneville

SPECIES	NO. ADULTS	FECUNDITY	EGG-TO-SMOLT SURVIVAL	NO. SMOLTS
Spring chinook	391,000	4500	0.015	13,196,250
Summer chlnook		5000	0.015	0
Fall chlnook	1,081,000	5500	0.050	148,637,500
Sockeye		2500	0.040	0
Coho	926,000	2500	0.010	11,575,000
Chum	1,392,000	2500	0.350	609,000,000
Summer steelhead	243,000	3500	0.010	4.252,500
TOTAL	4,033,000			78,661,250
ENTIRE COLUMBIA	16,320,000			1,351,215,000

Figure 1

Pre-development run sizes above and below Bonneville (NPPC 1986).

"Carrying capacity is defined as the greatest weight of fishes that a stream can naturally support during the period of least available habitat. The stream's carrying capacity limits the number and weight of salmonid smolts ultimately produced" (Burns 1971).

Production can be defined as" the quantity of fish material formed in the population during the given time, whether or not the fish in which it is incorporated survive to the end of the period"

--or-- "the number or weight of fish leaving the system at the end of the period" (Allen 1969).

Production includes"both a numerical component, determined by reproduction, immigration, mortality, and emigration, and a weight component primarily determined by growth. Thus all environmental features affecting any of these processes can potentially limit production" (Allen 1969).

Figure 2

A set of carrying capacity definitions.

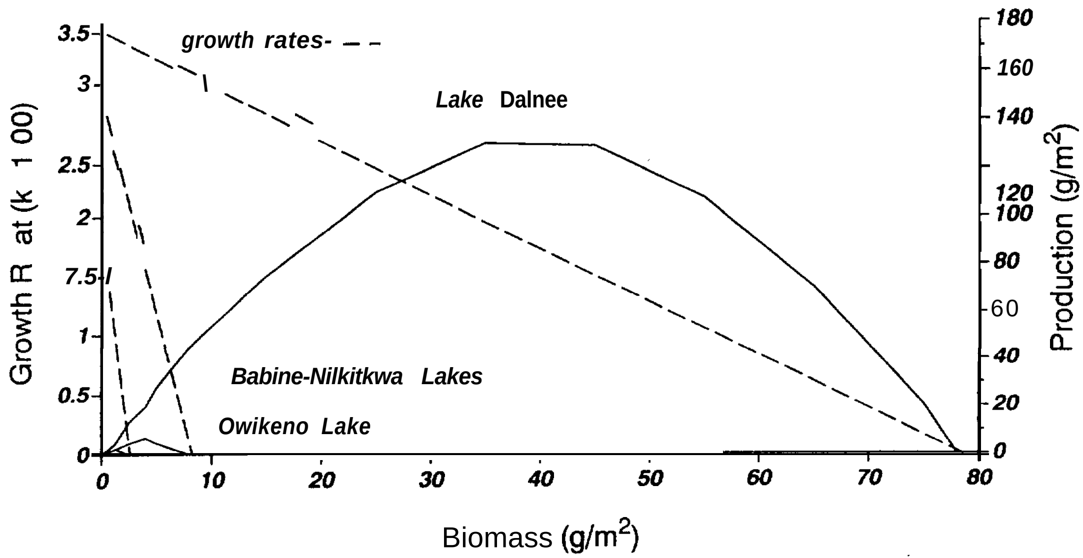

Figure 3
Juvenile sockeye salmon growth, biomass, and production at Lake Dalnee, Babine-Nilkitkwa Lakes, and Owikeno Lake (Warren 1971).

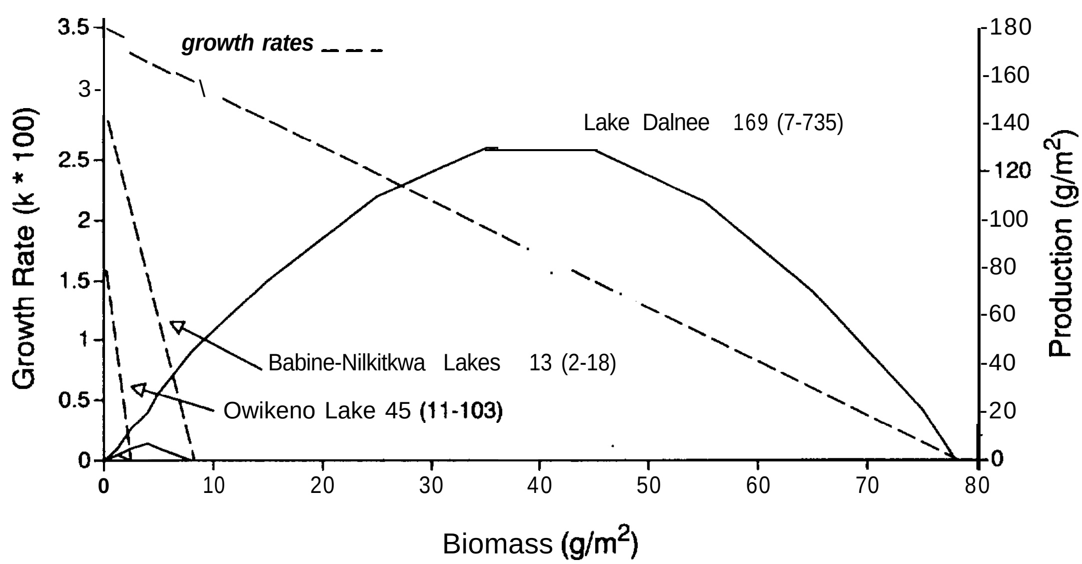

Figure 4
Sockeye salmon spawners per hectare (Burgner 1991) supported at Lake Dalnee, Babine-Nilkitkwa Lakes, and Owikeno Lake.

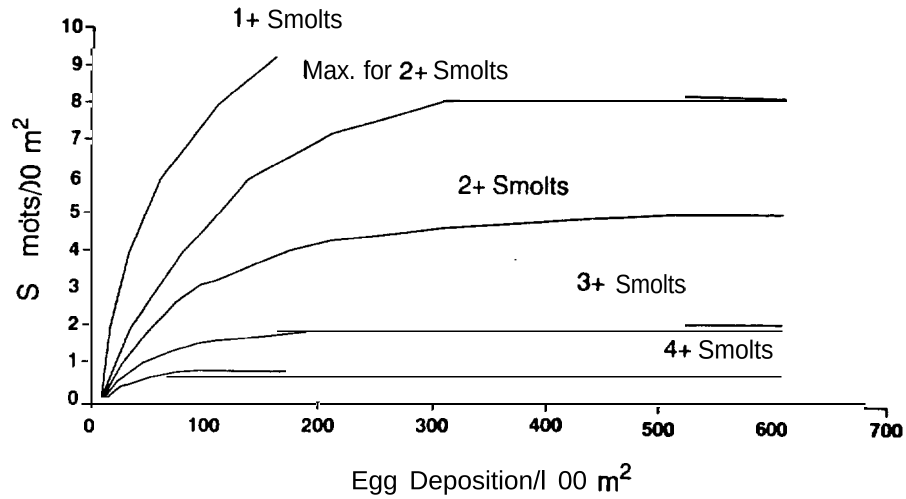

Figure 5
Estimated Atlantic salmon smolt densities versus egg deposition in New Brunswick rivers (Symons 1979).

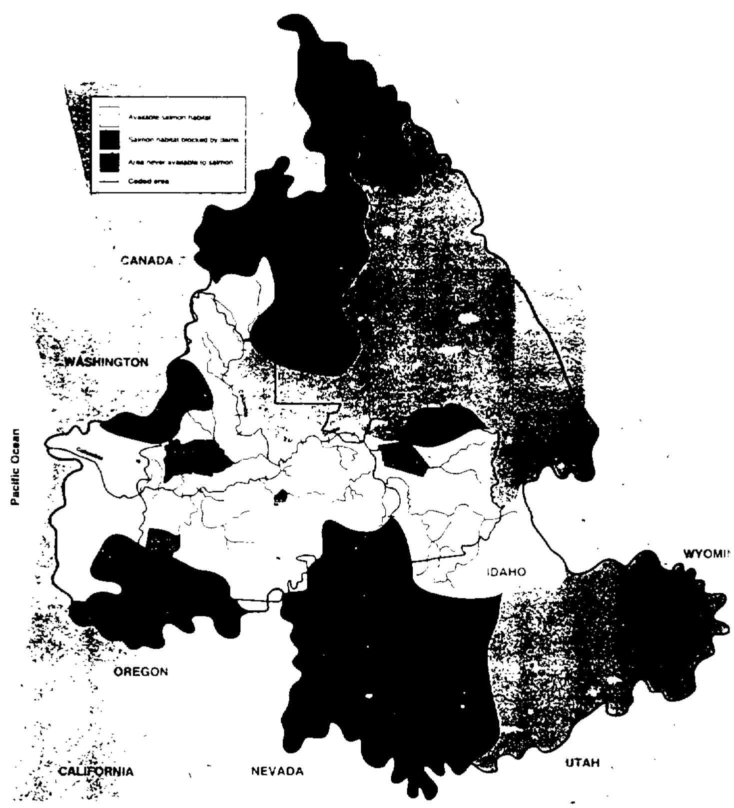

Figure 6
Map showing historic changes in quantity of salmon habitat in Columbia River Basin. Current anadromous-fish carrying capacity depends on unshaded areas.

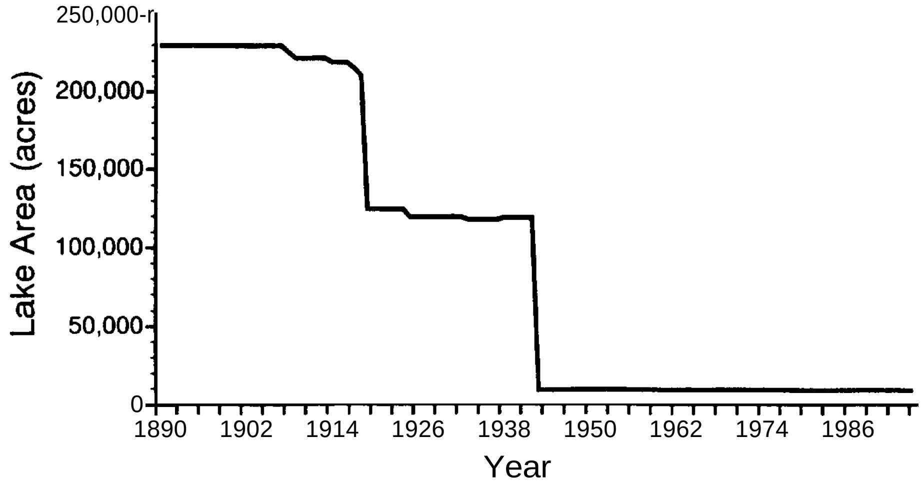

Figure 7
Historic loss of available habitat for sockeye salmon spawning and rearing in Columbia River Basin (CRITFC 1995).

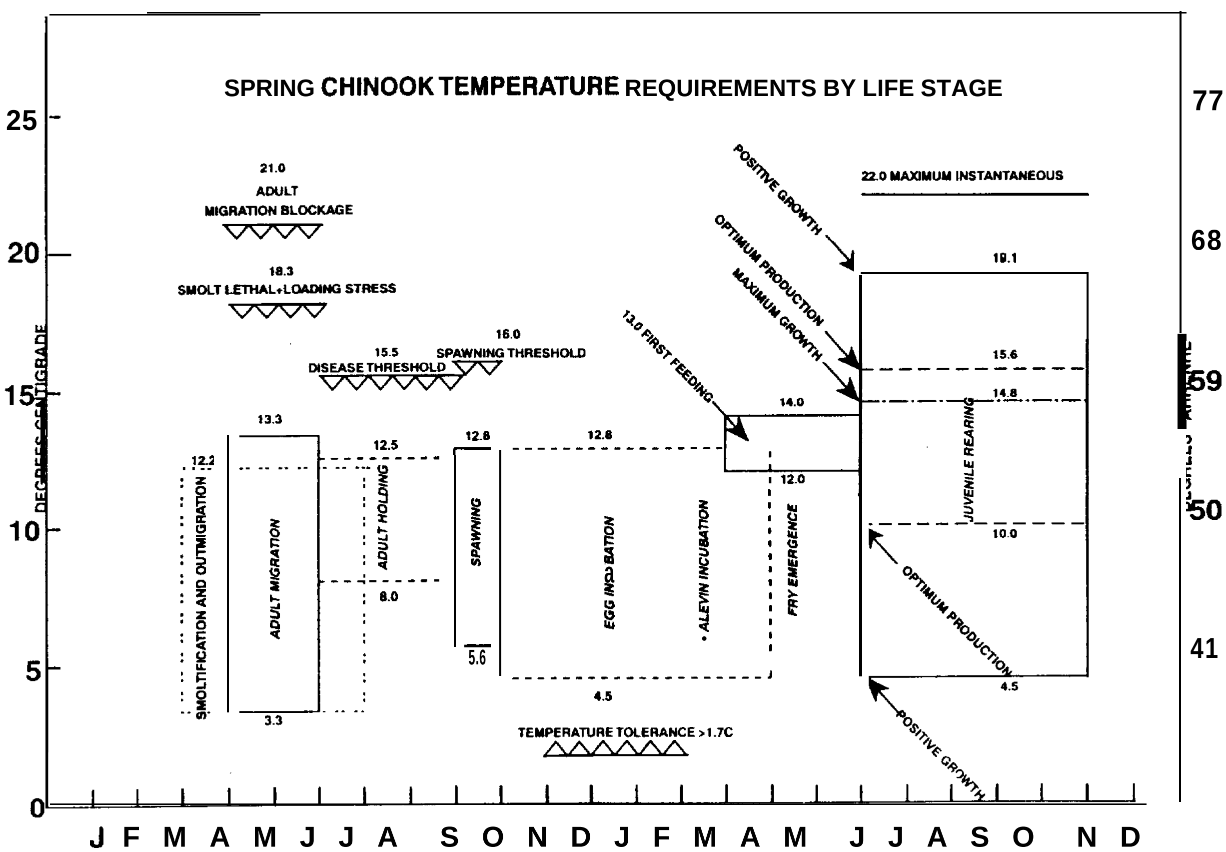

Figure 8
Summary of literature on temperature requirements by life stage of spring chinook salmon.

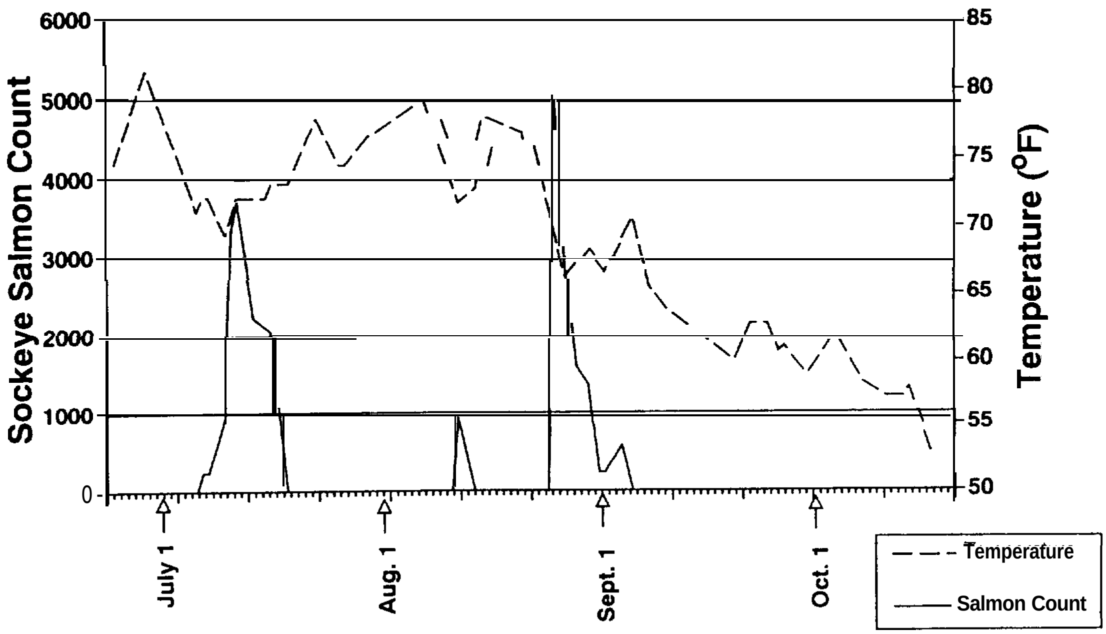

Figure 9
Adult sockeye salmon migration for 1992 through Zozel Dam into Lake Osoyoos, Okanogan River (Hatch et al. 1993), showing migration blockages.

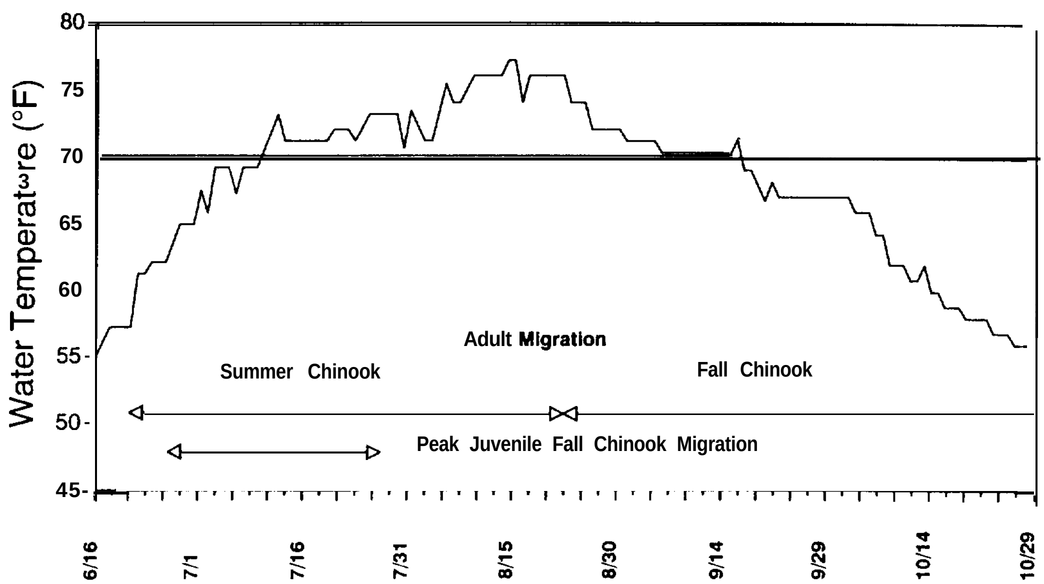

Figure 10
Lower Granite Reservoir temperatures in relation to timing of chinook salmon migration, 1990 (Karr et al. 1992).

Lakes: Morphoedaphic Index (MEI) = total dissolved solids/mean depth
Ryder (1965), Ryder, Kerr, and Regier (1974).

Large Floodplain Rivers:
Total annual yield = 112.47 (low water area/high water area)$^{0.81}$
Catch = $0.133A^{0.85}$ where A is basin area.
Welcomme and Hagborn (1977), Welcomme (1976). Authors recommend inclusion of duration of flood, conductivity, landuse on floodplain.

Small Streams:
Standing crop = $a + bX_1 + cX_2 + \ldots + nX_n$
$X_1, X_2, \ldots X_n$ = independent habitat variables, and
$a, b, \ldots n$ = regression coefficients
Fausch, Hawkes, and Parsons (1988).

Figure 11
Various models used to predict fish yield or biomass for lake, floodplain rivers, and small stream systems.

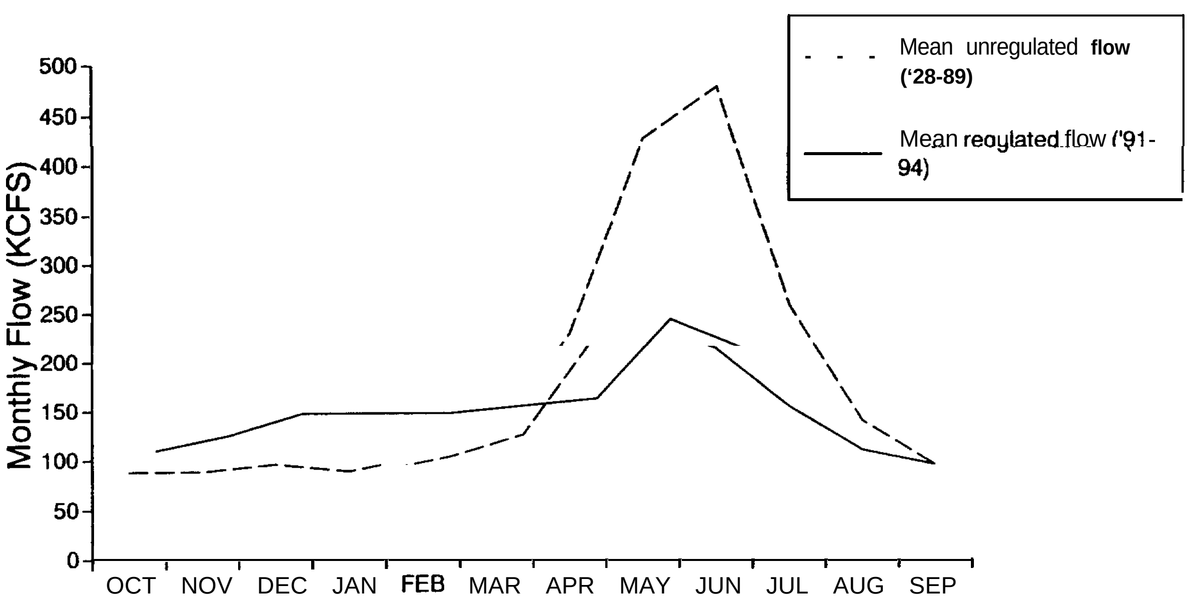

Figure 12
Current mean regulated flows (1991-94) compared with historic mean unregulated flows (1928-89) at The Dalles Dam, Columbia River (CRITFC 1995) showing use of floodplain area for juvenile outmigration.

1: Drainage basin variables	Reach elevation, drainage area, mean basin elevation
2: Channel morphometry variables	Mean depth, mean width, surface area, pool area, width-to-depth ratio, mean pool depth, gradient
3: Flow variables	Mean monthly flow, mean summer flow
4: Habitat structure variables	Area of all cover, length of undercut bank, area of overhanging riparian vegetation, area of rubble, boulder, and aquatic vegetation substrate
5: Biological variables	Number of fish species, species range
6: Physical variables (substrate and temperature)	Percent substrate embeddedness, mean annual water temperature, mean annual air temperature
7: Chemical variables	Dissolved oxygen range, pH rating, mean alkalinity, mean conductivity

Figure 13

Major categories of small-stream model variables used to predict standing crop (Fausch et al. 1988).

Drainage basin: drainage area, basin geomorphology

Stream network: longitudinal profile, spatial organization (e.g., proximity of winter rearing to summer rearing areas)

Stream segment: riffle/pool ratio
pool frequency

Channel unit: fine sediment
embeddedness
temperature
large woody debris
pool volume and depth
water flow

Figure 14

Habitat parameters at various hierarchical levels that influence carrying capacity and survival (source?).

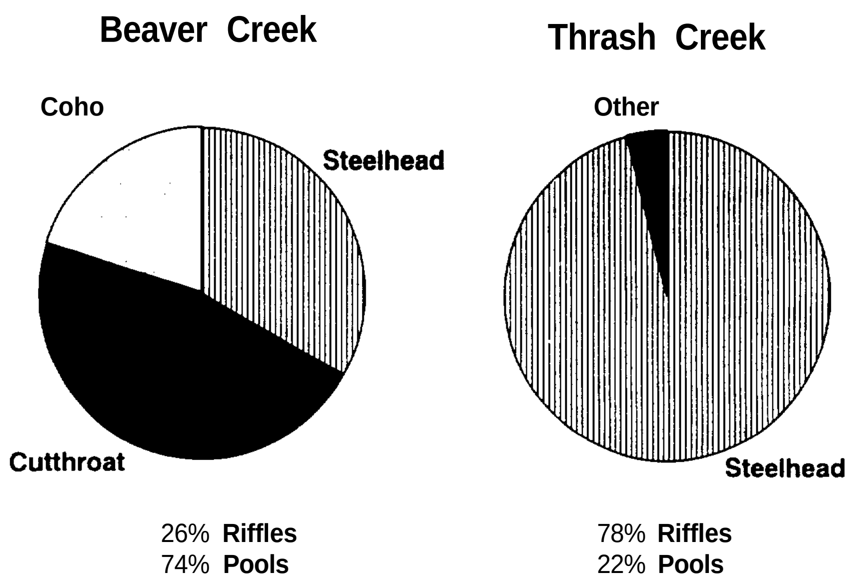

Figure 15
Riffle:pool ratio effect on fish community composition at Beaver and Thrash creeks (from Bisson as cited by Sullivan et al. 1987).

Adult migrant and pre-spawning survival: S1
S1 = f[passage survival, water temperature, primary pool availability, water discharge]

Egg-to-fry survival: S2
S2 = f[% fines in spawning gravel, scour depth and intensity of peak flows, water temperature, dissolved oxygen]

Fry-to-Parr survival: S3
S3 = f[predator, competitor, and stock density, food availability, light intensity (canopy cover and topographic shading), temperature, pool area, pool depth, pool frequency, cover factors (banks, LWD), low flows, substrate embeddedness, boulder frequency]

Parr-to-smolt survival: S4
S4 = f[primary pool area and frequency, LWD, bank cover, large boulder clusters, peak flows, water temperature (canopy cover)]

Figure 16
Habitat variables controlling survival by life stage.

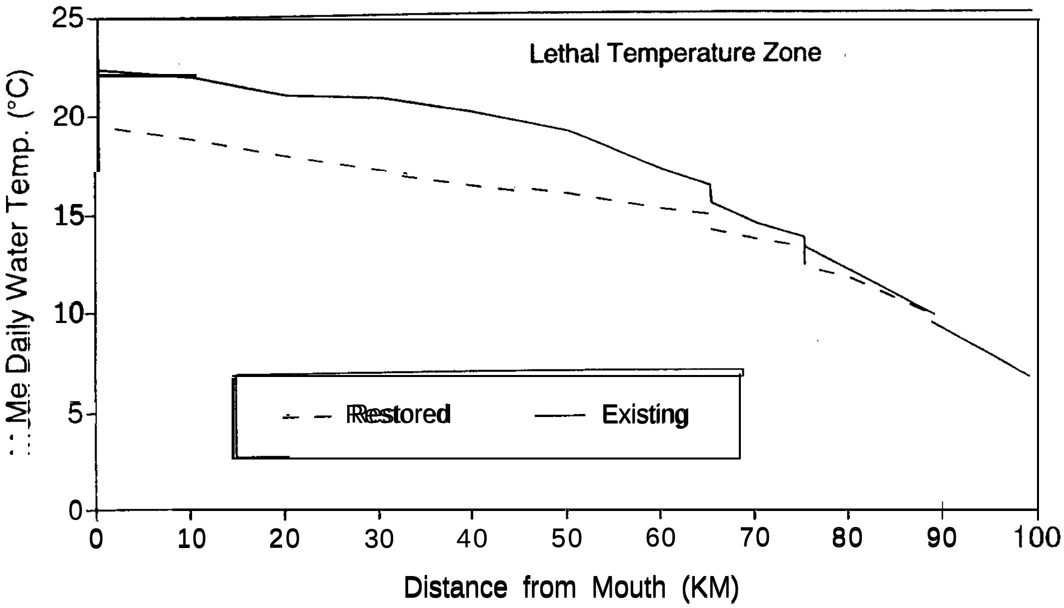

Figure 17
Impact of riparian and channel restoration on salmon habitat, Tucannon River, Washington (Theurer et al. 1985). Solid line shows current water-temperature increase on the mainstem. from the head\vaters downstream to the mouth.

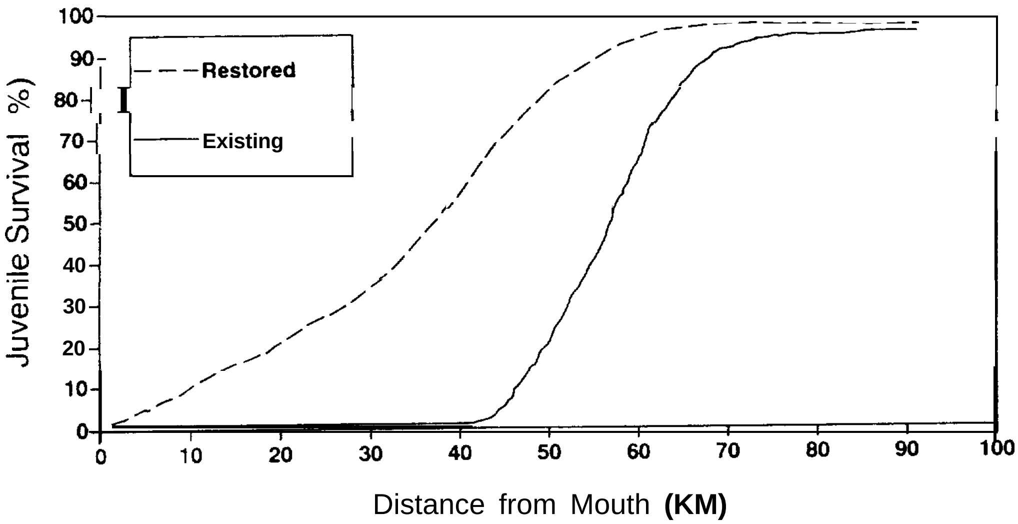

Figure 18
Theoretical survival of juvenile chinook salmon, Tucannon River (after Theurer et al. **1985).**

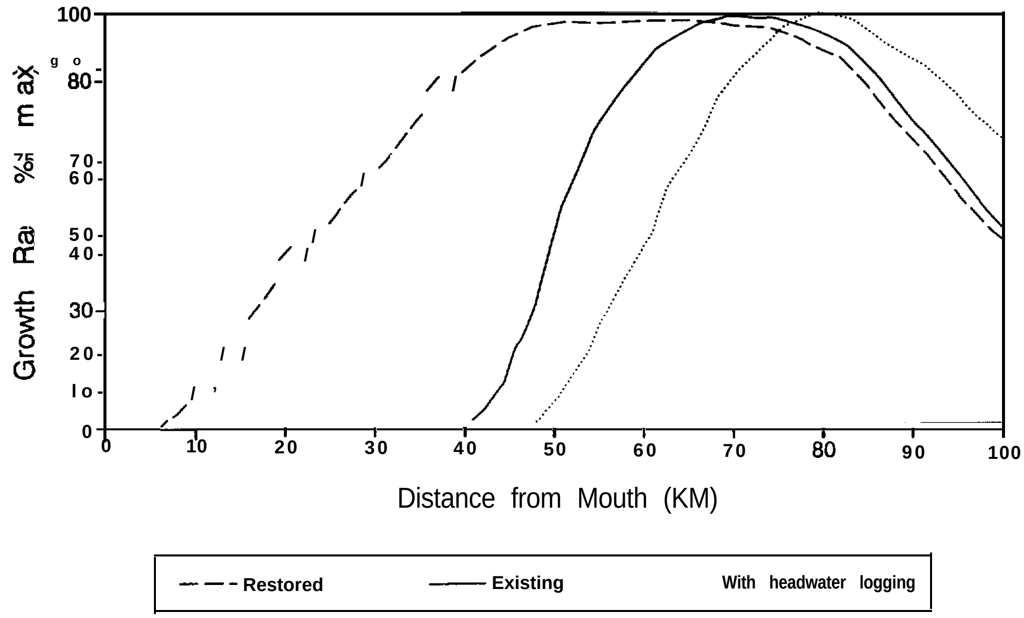

Figure 19
Theoretical growth rate of juvenile chinook salmon, Tucannon River (after Theurer et al. 1985).

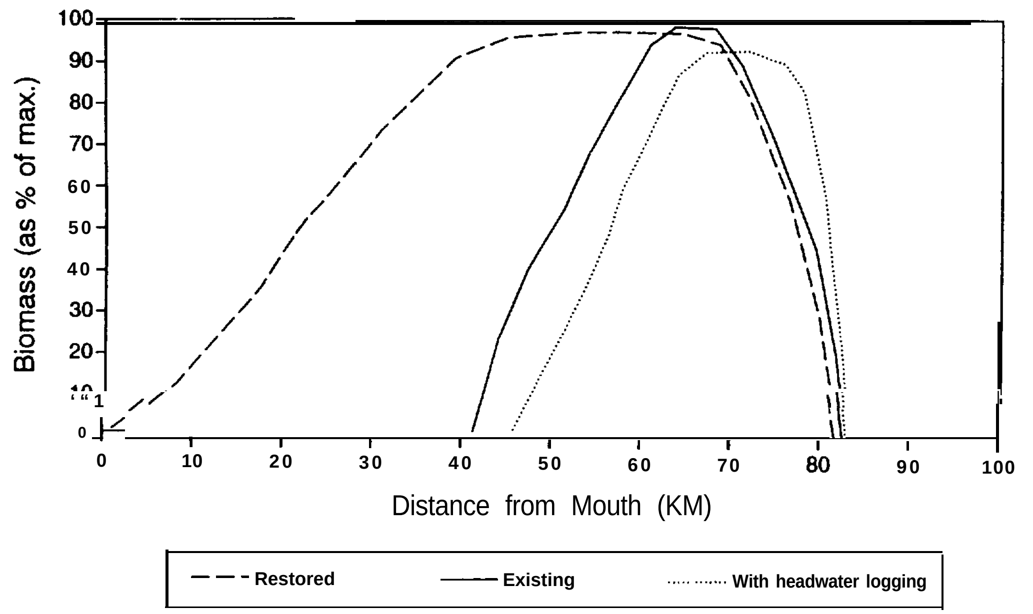

Figure 20
Theoretical biomass of juvenile chinook salmon, Tucannon River
(after Theurer et al. 1985).

Ecoregion	Watershed	Str. System	Valley	Riparian	Segment
Capability Proxies					
Regional class, potential natural vegetation, soil type, air mass type, latitude.	Drainage area, mean annual pre-cipitation, mean annual snowfall, glaciers, topo-graphic shading, mean elevation.	Elevation of stream mouth, longitudinal pro-file.	Gradient, valley width, sinuosity.	Potential riparian community.	Channel gradient bankfull width and depth, lithology.
Performances					
				Cover density, cover quality, canopy gap, tree height, mean air temperature.	

Figure 2 1

Water-temperature performance in relation to capability and performance of landscape components.

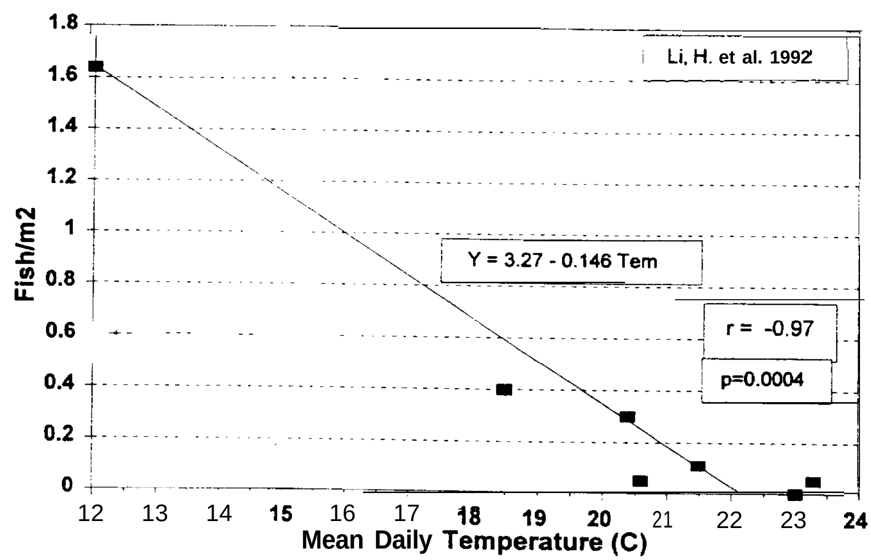

Figure 22

Effect of mean daily temperatures on densities of stenothermal fish in the John Day River (Li et al. 1992).

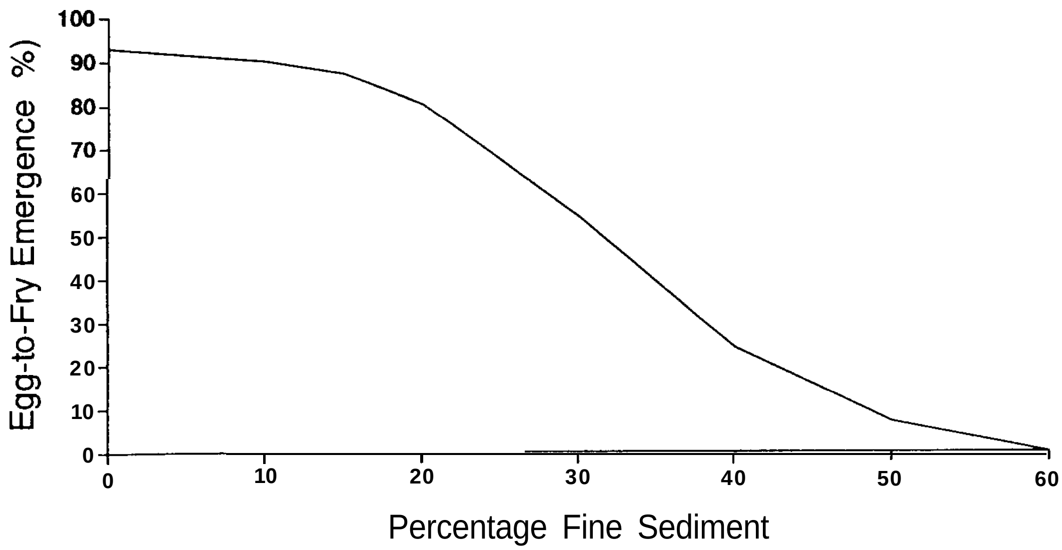

Figure 23
Relationship between percentage of fine sediment and chinook salmon survival to emergence (USDA Forest Service 198 1, 1983).

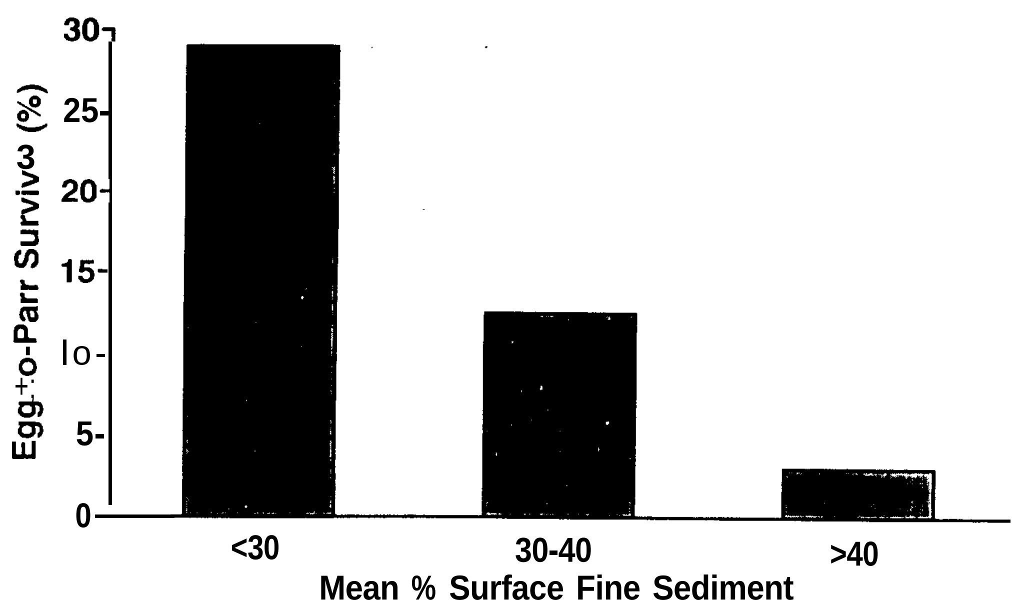

Figure 24
Relationship between mean percentage of surface fine sediment and survival of spring chinook salmon in the middle fork Salmon River, Idaho (Scully & Petrosky 1991).

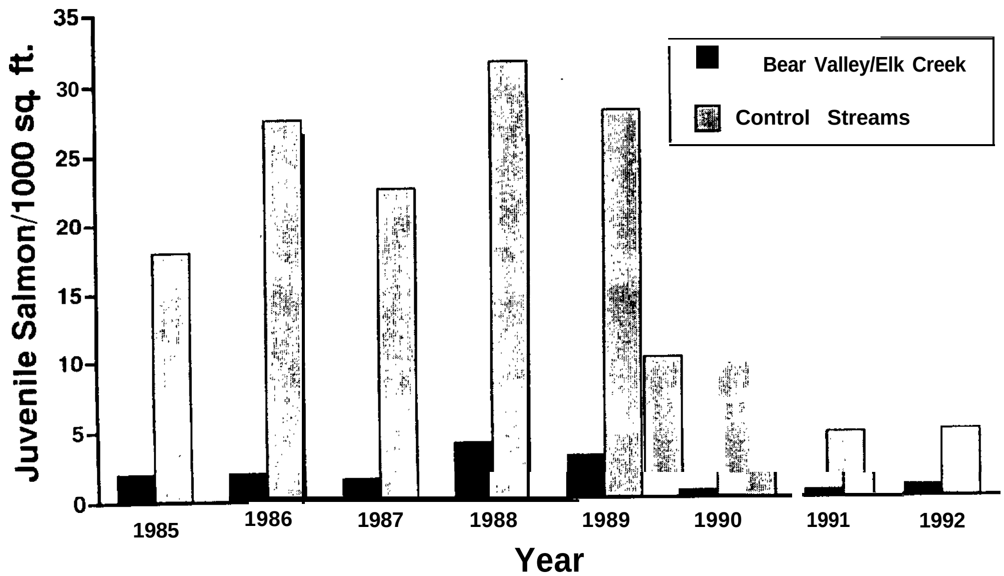

Figure 25
Relationship between fine sediment levels and density of juvenile spring chinook salmon in the Bear Valley and Elk Creek systems of the middle fork Salmon River, Idaho (source?).

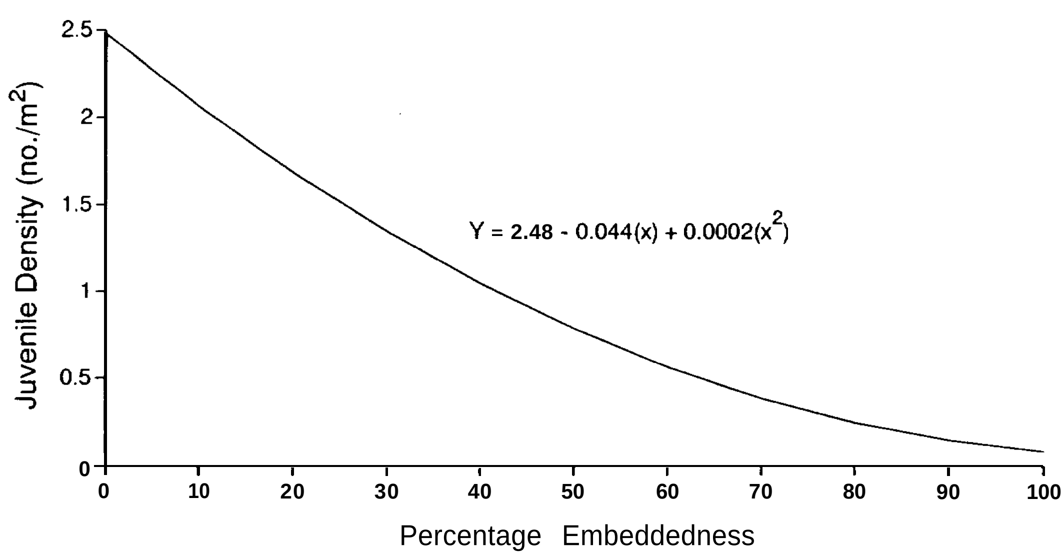

Figure 26
Relationship between summer carrying capacity of juvenile chinook salmon and cobble embeddedness (USDA Forest Service 1983).

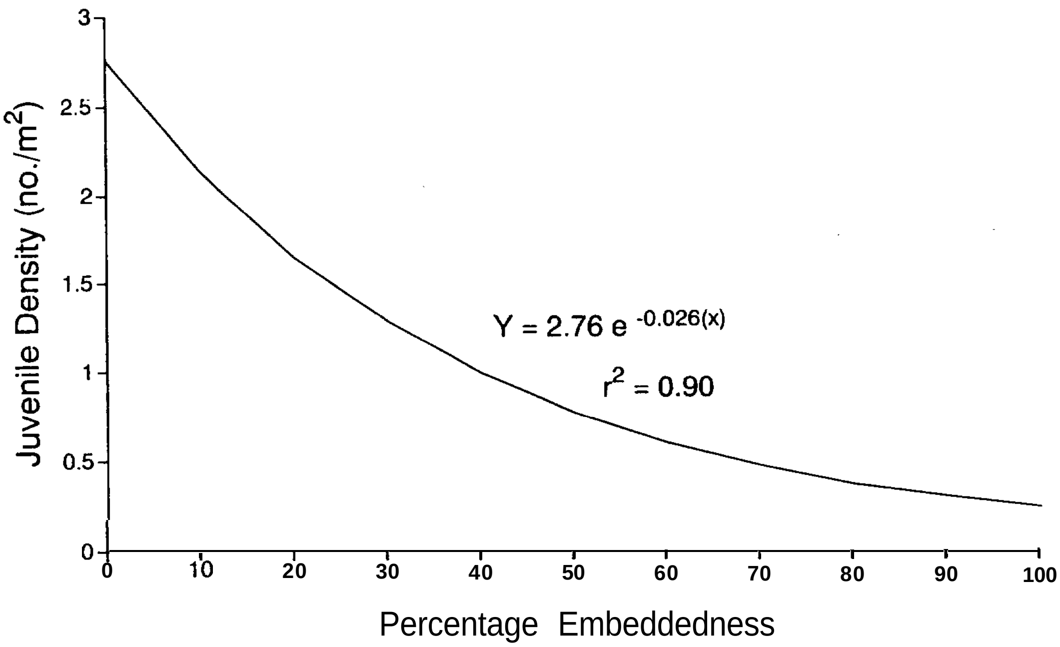

Figure 27
Relationship between winter carrying capacity of juvenile chinook salmon and cobble embeddedness (USDA Forest Service 1983).

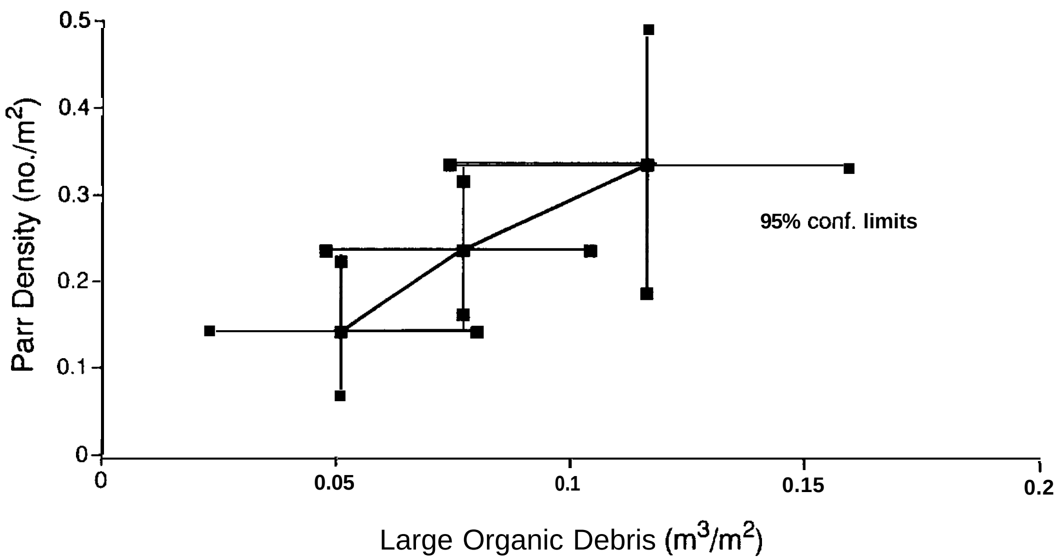

Figure 28
Relationship between large woody debris during winter and densities of coho salmon parr in a southeast Alaska stream (Murphy et al. 1986 as cited by Bisson et al. 1987).

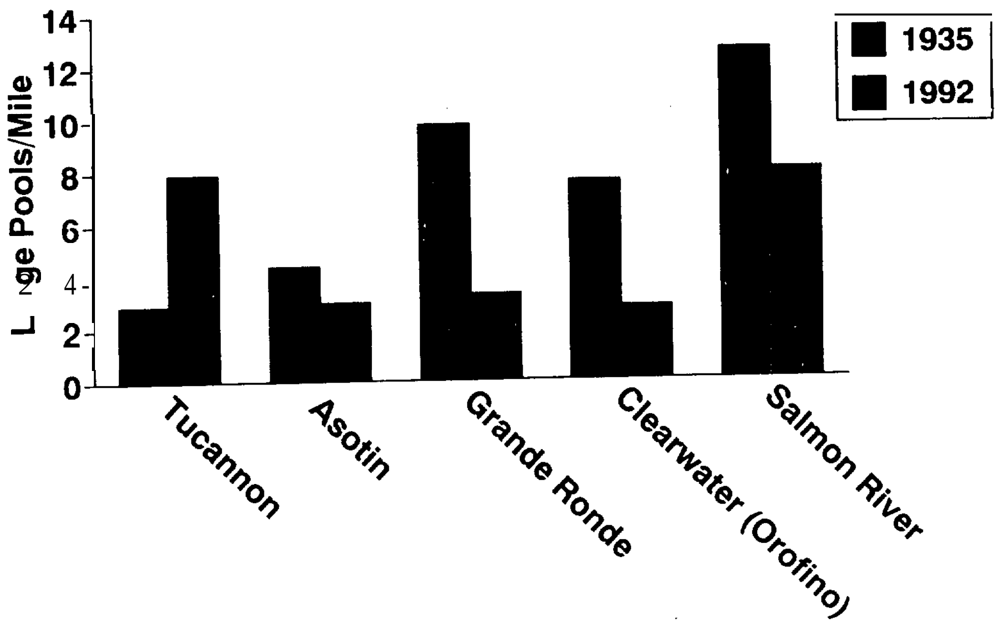

Figure 29
Loss in frequency of large pools in streams of managed watersheds, Snake River Basin (Sedell & Everest 1990, McIntosh 1992, McIntosh et al. 1994).

Capacity as a component of performance

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Salmon in the Columbia River comprise a hierarchy of species, populations, and life-history patterns. At any level in the hierarchy, we can describe performance of salmon in terms of three closely tied components: diversity, productivity, and capacity. By diversity, we mean multitude of pathways through life; the diverse ways for salmon to solve the problem of a varying environment. Productivity captures the density-independent aspect of survival; survival when density of similar organisms is not a factor in survival. Capacity is the density-dependent component of survival. These three components are shown (Fig. 1) as corners in a triangle to emphasize the point that they are interlinked parts of salmon performance.

The necessary quality of diversity implies that different population segments perceive and respond to the environment differently. They do this because differences in life-history pathways cause them to experience the river differently -- they do not move in unison. They also perceive and respond to similar conditions differently because of their backgrounds (prior life experience and genetic predisposition). The existence of diversity and the necessity to promote it mean that capacity as a component of performance must be understood in the context of diversity.”

We sometimes think of diversity and productivity as measures of quality, and capacity as a measure of quantity. Through its life cycle, the salmon will experience conditions that vary in both quality and quantity. Performance, which is the gauge of the values that can be extracted from the resource, is measured over the full life cycle. Moussali & Hilborn (1986) show that the cumulative (over the full life cycle) capacity is a function not only of the component (life-stage specific) capacities, but also of the component productivities. Therefore, in order to understand the role of capacity at a single life stage. we need to know capacities and productivities for all life stages. We cannot manage quantity and quality independently.

In order to offer useful advice to direct research on capacity, we need a framework that incorporates a more complex notion of performance than the one implied by the Council’s measure (7,lA). Such alternative theories or frameworks must be taken into consideration in the design of future research.

[5] **Diversity as a characteristic of the environment reflects the multitude and complexity of connected pathways that the salmon have available to bring their life cycles to closure.**

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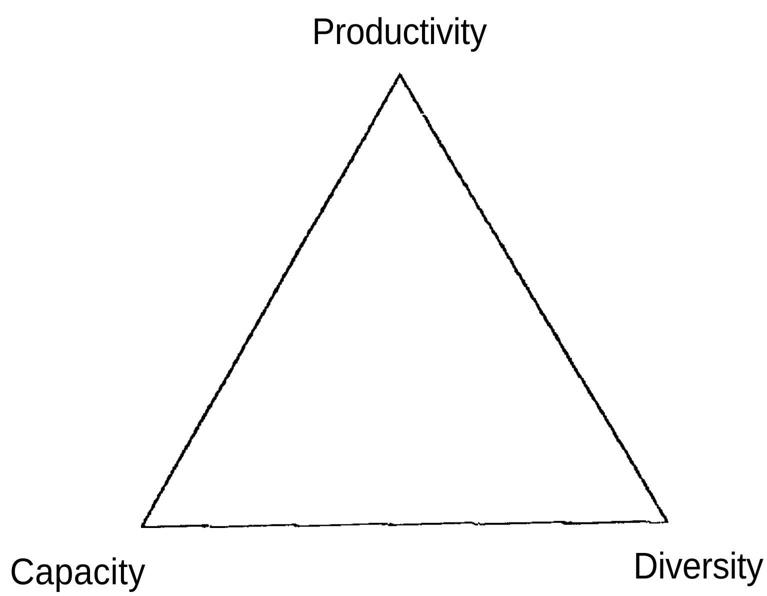

Figure 1
A measure of performance, highlighting the point that the three components of performance are closely interrelated.

Ocean carrying capacity

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We are all aware that the carrying capacity for Columbia River salmon depends on freshwater, estuarine, and marine conditions. I will talk about the marine environment. My first major point is that the ocean carrying capacity varies greatly in space and in time, just as it does in estuaries and in fresh-water. It varies seasonally, year-to-year, and on an inter-decadal scale. Large-scale changes in ocean and freshwater climates have affected the production of salmon in the Columbia River and are important considerations in carrying capacity and survival.

Some old data by McKeman et al. (1950) on coho salmon catches in different river systems, from the Columbia all the way down to the Coquille in Oregon, show strong similarity among the catches in different rivers, especially in the latter years. Peaks and troughs often coincide. This is an indication of large-scale, simultaneous regional effects on the catches of coho in these different river systems, suggesting common climactic or large-scale events.

Data on run sizes and catches of chinook salmon from the Central Valley in California up to the Columbia River also show similar interannal trends (Fisher & Pearcy, unpubl.; Fig. 1). Note that the peak in catches between about 1986 and 1988 is almost universal, especially for fall-run chinook. These good return years were produced by smolts that entered the ocean after the big El Ninio of the century, in 1982-l 983. Perhaps conditions were better after the El Niiio because of fewer competitors or predators. This El Niño "rebound" occurred for most stocks except for the upriver spring chinook. Spring-run chinook are stream-type fish that move rapidly through the river and estuary and then migrate swiftly up north into subarctic waters. On the other hand, Columbia River upriver brights migrate north but at a much slower pace. Trends for the upriver brights in coastal waters of the California Current are similar to those of the other fall chinook, suggesting that early ocean environment is important in survival.

A major change in the climate, not only of the Columbia River or the West Coast, but of the world, occurred in the late 1970s (Kern 1995). This change had many effects. Ebbesmeyer et al. (1990) reported 40 variables that had jumps, either up or down, around 1976. In the Pacific Northwest, precipitation decreased and sea temperatures increased after 1976. Graham (1995) illustrated that sea surface temperatures during 1977-l 982 were much higher than those during 1971-1976 in the world ocean, especially in the Pacific Ocean where the temperature anomaly was almost 1 °C warmer than during the previous time-period.

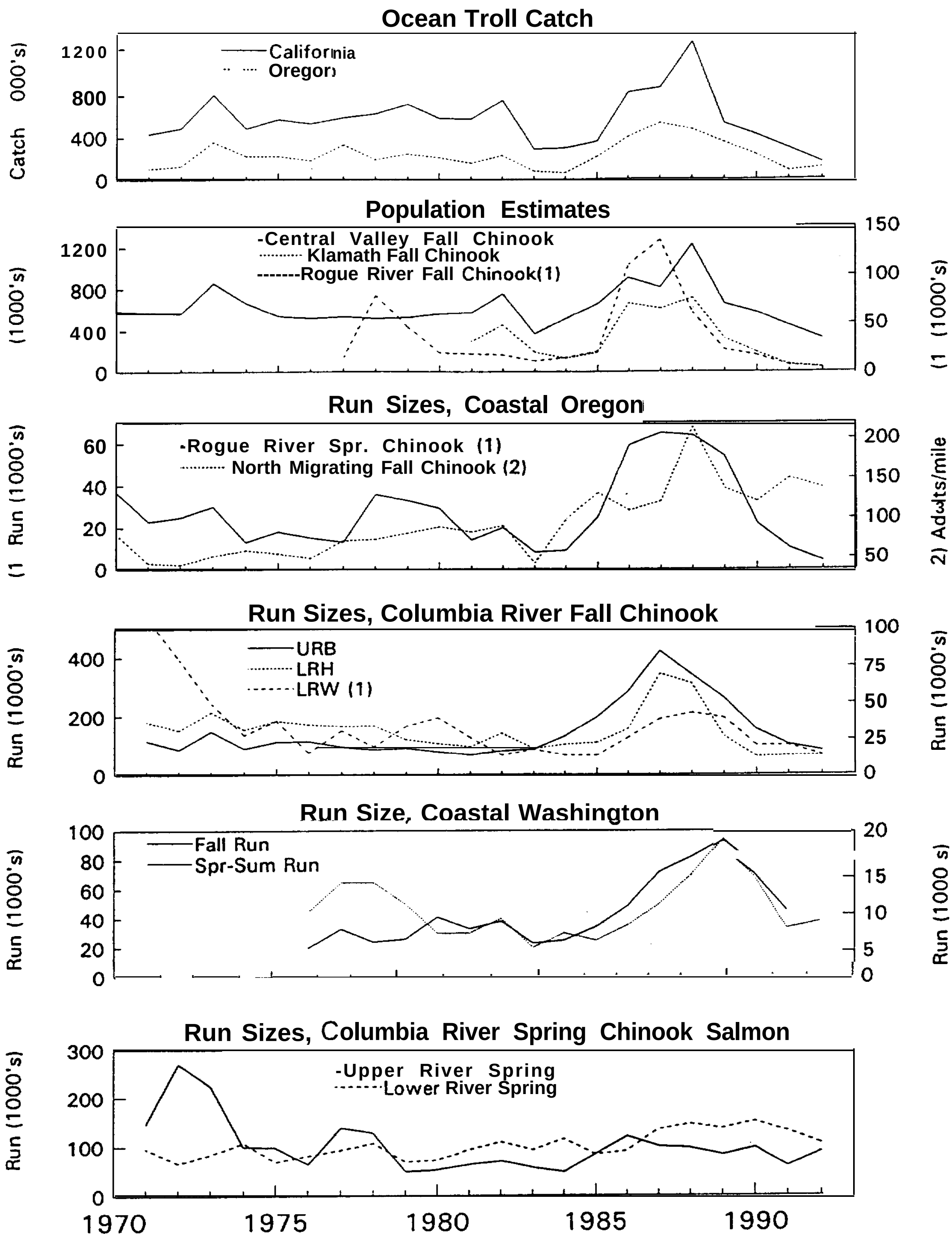

Figure 1
Run sizes and catches of Pacific salmon from central California to the Columbia River, 1970-1992.

Sea temperatures along the West Coast were high after 1976, from California through Alaska. According to Graham (1995), this recent episode of global warming was caused by intense precipitation and release of latent heat in the tropical Pacific, the spawning grounds of El Niños. This apparently changed the jet stream, precipitation patterns, and temperatures around the world.

The Southern Oscillation Index, an atmospheric index of El Niño events, also declined abruptly after 1976, indicating El Niño conditions in the tropical Pacific. We had a big El Niño in 1976, a big one in 1982-83, another in 1987, and then a series of El Niños in the early '90s. Since 1976, the Southern Oscillation Index has been low for an unprecedented period of time (Trenberth & Hurrell 1995).

The sea-level atmospheric pressure in the North Pacific during the winter also decreased sharply after 1976. This indicates a deeper Aleutian low and a changed pattern of atmospheric circulation, with advection of warm air and warm water from the south and intensification of circulation in the Gulf of Alaska and the Alaska gyre (Trenberth & Hurrell 1994). Farther south in the California Current system, off Oregon, sea temperatures generally increased after 1976 and upwelling decreased.

All these factors have changed the carrying capacity of salmonids in the North Pacific. The Oregon Production Index (OPI) data for public hatchery coho salmon is one of the best data sets available on survival of salmon. Almost 80% of these OPI stocks are of Columbia River origin. Survival rates were high (-6%) from the period of the early '60s to about 1975, and then they dropped precipitously between '75 and '76 when this climate-regime shift occurred. Since that time, survival rates have been low, with the exception of 1985 and a few other years (Nickelson 1986). Survival was much lower during the 1982-83 El Niño and during the prolonged El Niños of the early '90s (Pearcy 1992, Pearcy In press).

Production of salmonids in the California Current and the Alaska Current systems appears to be out-of-phase. Washington, Oregon, and California coho catches decreased after 1976 , while those of Gulf of Alaska pink salmon increased (Francis & Sibley 1991). Periods of high or low production may last for 20 to 30 years. Now we are in this area of low production in the California Current and high production in the Gulf of Alaska. Warm sea temperatures in the northern range of salmonids, associated with a deep Aleutian low and intense cyclomic circulation in the Gulf of Alaska, apparently favor high production in the northern North Pacific Ocean. Whereas warm temperatures in a weakened California Current, at the southern end of salmonid distributions, are unfavorable to high survival .

Upwelling is thought to be the major factor that affects production of salmon stocks in the California Current. Nicholsen (1986) showed a positive and significant correlation between coastal upwelling during the summer at 42°N and smolt-to-adult survival of hatchery OPI coho. This suggests a mechanism that connects upwelling and ocean productivity to survival, However, after 1976, a negative but nonsignificant relationship occurred between coho survival and upwelling (Pearcy In press). Some years, like 1991, had fairly strong upwelling with very low survival. And 1985, a very good survival year, had very low upwelling. Many of the recent low-survival years were El Niño years that were unfavorable for high production of coho salmon.

Deterioration of the OPI coho survival-upwelling relationship is probably related to the effectiveness of upwelling in pumping cool nutrient-rich waters. Since 1976, upwelled water may actually be coming into the euphotic zone with a thick layer of warm water at the surface and a deeper thermocline, which often occurred during recent years, so upwelled waters are depleted in nutrients. Off southern California, Roemmich & McGowan (1995) reported a drastic reduction in zooplankton standing stocks between 195 l-57 and 1987-93. They attributed this to the increased thermal stratification during recent years and less effective upwelling. Another factor that affects zooplankton standing stocks is input of subarctic waters from the north. Since 1976, the California Current has been weak, so both ineffective upwelling and less advection of subarctic water into the California Current have decreased the productivity of the system.

What controls the production of salmon, or their carrying capacity, in the ocean? Is it ocean productivity and food, predation, or other factors? Most studies indicate that the amount of food consumed by juvenile salmon in the coastal ocean is very small relative to the overall production of potential prey (Peterson et al. 1982, Brodeur et al. 1992), suggesting that food production is not limiting.

Predation may be an important factor. During periods of low ocean productivity, when forage animals are at low levels of abundance, salmon smolts may be preyed on more intensely. Moreover, during warm years, there is an influx of predators from the south. such as Pacific hake and jack mackerel and Pacific mackerel, that are known to prey on juvenile salmon smolts. So, during warm ocean years, not only is ocean productivity low but predators on salmonid smolts may increase. Slow-growing fish that aren't getting enough food are certainly going to be preyed upon at a much higher rate than fish that are growing rapidly and so can escape predators.

Finally, I'd like to cite a paper by Jim Anderson (1995) that I just read that clearly illustrates our dilemma of separating natural climatic cycles from man-induced events on Columbia River salmon. He used a 5-year running average of the Pacific Northwest Index (PNI), a combined index of temperatures on the San Juan Islands, rainfall at Cedar Lake, Washington, and snowpack on Mt. Rainier as of March 15 to show "cool and wet periods" vs. "warm and dry periods" since 1900 (Fig. 2). "Cool and wet periods" are considered good for survival of salmon generally in southern regions, and "warm and dry periods" are associated with lower survival. Anderson related episodes of these cool/wet or warm/dry periods to Columbia River chinook salmon catch.

The early 1900s were a cool/wet period of high survival when catches were high. A warm/dry low-survival period ensued from about 1923 to 1944. This coincided with the rapid decline in catch rates of chinook salmon due, in part, to overfishing, but

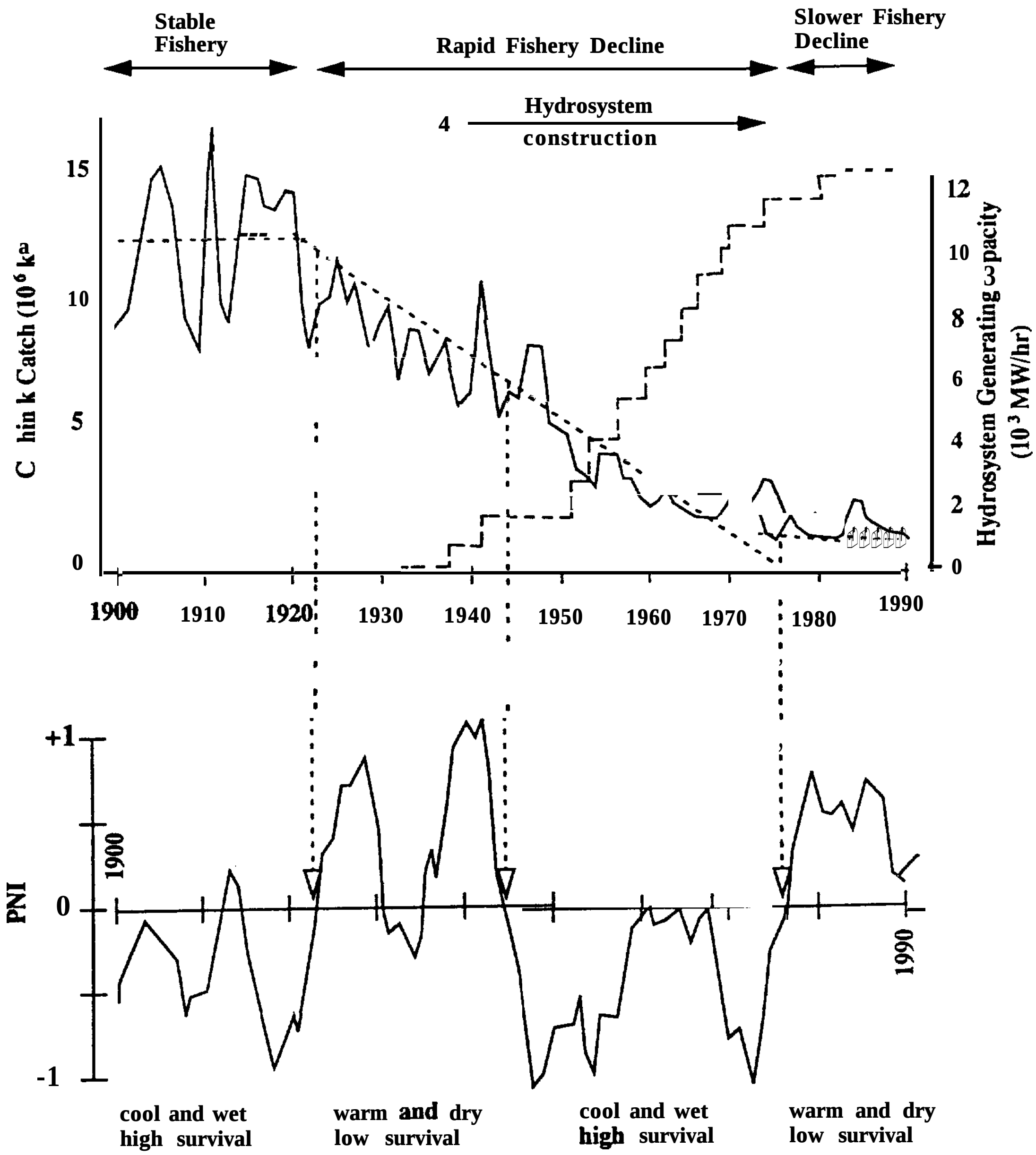

Figure 2

Patterns of decline in Columbia River chinook salmon fishery and the Pacific Northwest Index that characterizes warm/dry and cool/wet climatic regimes.

confounded with climate changes. From about 1945 to 1976, another cool/wet episode should have been good for production, but the decline in catches of chinook salmon continued, largely because of over-fishing but also because of massive hydro development on the Columbia. Anderson speculated that catches would have rebounded if it weren't for the many dams constructed. Lastly, after 1976 we've seen a warm/dry period of poor survival. The decline of catches has leveled off, perhaps because of restrictions on fishing and efforts to restore the Snake River chinook salmon.

I would like to conclude by saying that we really need to understand the mechanisms that affect the survival or production of salmon. Man has a great impact on the Columbia River system and on freshwater survival of smolts and adults. We have also caused high ocean fishing mortality. We need to be able to separate man's impact from the natural fluctuations in the environment in order to effectively manage or restore stocks. If we have a turnaround now to a cool/wet period with high survival rates and catch rates, it will be tempting to attribute this to our management and restoration on the Columbia River rather than ocean/freshwater climate. And then, if salmon stocks never fully recover and freshwater habitat continues to decline, and we enter another period of poor ocean climate, populations may decline to dangerously low numbers (see Lawson 1993).

BOB EMMETT: I'm Bob Emmett with the National Marine Fisheries Service. And I was wondering if you have had any indications of change in the dynamics of the plume?

MR. PEARCY: Absolutely.

BOB EMMETT: Do you think that has contributed at all to the changes in some of the salmon survival studies?

MR. PEARCY: Yes. Now, flows in the wintertime are about equal to the flows in the summertime. Before the dam era, you had peak flows and a large plume that developed in the spring, during the time of smolt outmigration in May and June. We found our highest catch rates of chinook salmon smolts in the plume. The survival rates of coho salmon smolts were high during 1982 and 1985, years with a well-developed plume that jetted to the south (1982) or offshore (1985). When that plume is well-developed, it may transport,fish offshore where the predation rates are lower than when that plume is close to shore. So I think the plume structure may be very important, but unfortunately we don't have any good data to verify this. This is something that can be studied by satellite to correlate ocean temperature, chlorophyll, and currents, and then correlate this with survival of some Columbia River stock. That's a good point, Bob.

AUDIENCE: You made a comment about trying to sort out the mechanism that explains this. What kind of progress has been made there? It's hard -- given the lengthy data on survival and growth rates -- to figure out what happened. Is there ongoing work to try to get a better handle on this stuff?

MR. PEARCY: There are some ongoing ocean field studies, but I don't know of anything relative to the Columbia River salmon. Maybe Bob Emmett has some other ideas on this. We need to look at mechanisms affecting survival in the ocean and try to nail them down. Ocean productivity and growth may be closely coupled. You can study growth rates by looking at wire-tagged fish. You can look at scales. You can look at condition factors and get some growth-rate information. For the years that we sampled out in the ocean, which was from 1981 through 1985, we had two years of horrible survival, which were '83 and '84, El Niño years, and two years of good survival, '82 and '85. We found no indications that growth rates, condition, or stomach fullness were much lower in these "poor survival years" of '83 and '84 than in the good survival years 'of 82 and '85 (Fisher & Pearcy 1988). This is just one small data set, but it led us to reject the hypothesis that survival was associated with chronic food shortages and to speculate that predation was a major factor in controlling the survival rates of smolts The predation hypothesis should be evaluated, because not enough attention, at least in Oregon and Washington, is paid to predation. That might be a key factor.

AUDIENCE: Bruce (unintelligible) from the Northwest Power Planning Council. I believe up in Alaska, they are doing some work on that right now. Ted Cooney out of Alaska in Fairbanks, Prince William Sound.

MR. PEARCY: The Auke Bay Lab also has plans to do some work on ocean sampling of salmonids using nets and acoustics.

MR. BISSON: I have seen some evidence recently, I think, presented by Jack Helly, looking at the average size and age at maturity of Pacific salmon. And the trend appears to be downward for size and later for maturity, all the way up and down the coast. Can you suggest why that might be so?

MR. PEARCY: That certainly is the case, and I think the obvious reason is limited carrying capacity in the ocean and less favorable conditions for growth. There is good evidence for this from some of the hatcheries, both for pink salmon and Japan chum salmon. You reach a certain plateau in numbers of fish released, and the growth rates or size-at-age start to fall off. You have the fish coming back at smaller sizes. I think that's probably what's happened since 1976 for stocks for some stocks in the southern part of their range where ocean productivity is low. Up north, where we've had very high production rates and record catches, actually exceeding historic highs, competition among salmon for food probably explains reduced growth rates. So there's evidence for a limited carrying capacity that affects growth where salmon production is presently both low and high.

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Effects of supplementation with hatchery fish on carrying capacity and productivity of naturally spawning steelhead populations

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I would like to shift gears a bit and talk less about habitat quality and quantity and more about the genetic quality of the fish population itself, as affected by supplementation. Basically, this invitation to talk gave me the excuse, or prodded me, to look at the available data and see what it says about the likely effects of hatcheries and supplementation programs on the production of fish populations. So my purpose is to explore the consequences of supplementation to carrying capacity, productivity, and the combined production (i.e., the hatchery and natural production) in a supplementation system. I'm focusing on supplementation in large part because, at least in the past and I think presently, supplementation has been presented as a major component or tool for restoration of anadromous salmonids in the Columbia River system.

My findings suggest that supplementation may be far less beneficial than commonly estimated. The available data suggest that we should expect significant and substantial reductions in the carrying capacity and productivity of the natural spawning population, such that the combined production of the system -- that is, again, both hatchery and wild production -- may be only a third of the expected, even when we are involved in a relatively conservative supplementation program, where only wild fish are used in the hatchery program. Such a program is conservative because it does not allow an "established hatchery stock" to develop.

One important lesson that I would like to convey is that carrying capacity is a function of genetic quality as well as of the things that Peter Bisson and Robert Wissmar and others were talking about, the quality of habitat itself. Another lesson is that hatcheries can be and are powerful agents for effecting genetic change.

So what do I base all this bold talk on? There are some highly relevant data, albeit not as much as we would like, but there are some good data from several studies dealing with steelhead (Oncorhynchus mykiss) where survival has been compared between the offspring of hatchery and wild fish. Figure 1 summarizes that data, in which the Y-axis is the survival of hatchery fish relative to wild fish. Quite often when I say "wild fish," I mean progeny of wild fish. By examining progeny, the studies have evaluated genetic differences between hatchery and wild fish. When this relative survival is 1, the survival of hatchery fish is equivalent to that of wild fish; if it's >I, as in one case here. the hatchery fish are surviving better than the wild fish; when it's < 1, the hatchery fish are surviving worse.

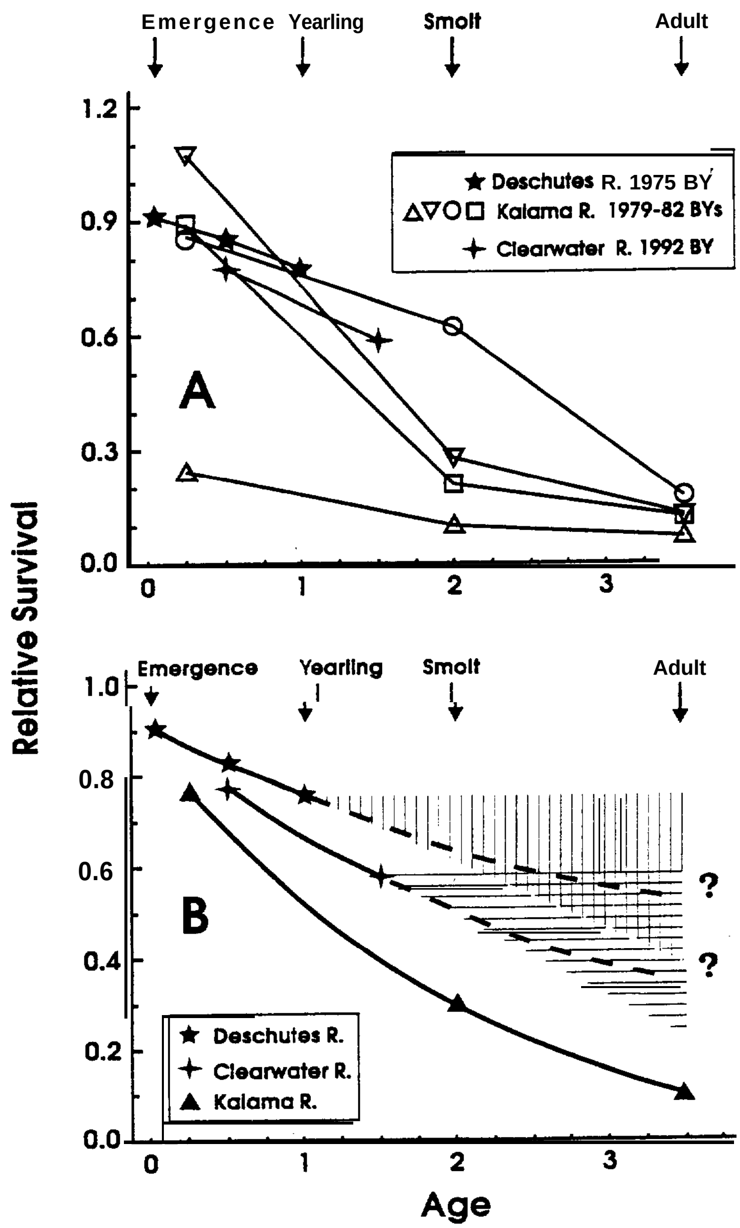

Figure 1
Survival for offspring of hatchery steelhead rearing in natural streams (or at sea) relative to that for offspring of wild steelhead at various ages or life-history stages. Relative survivals were evaluated from the eyed-embryo stage in Oregon's Deschutes River (stars; Reisenbichler & McIntyre 1977), unfertilized eggs in Washington's Kalam River (open points; Leider et al. 1990) and swim-up fry in Idaho's Clearwater River (crosses; NBS unpubl. data). (A) Data are given for each year-class separately. (B) Data for the Kalama River (squares) are arithmetic means from the four year-classes. Curves were fitted by eye. Dashed lines represent extrapolation of the data from the Deschutes and Clearwater rivers following a trajectory similar to that for the Kalama River. Shaded areas represent reasonable limits for these extrapolations.

So in these graphs (Fig. l), I've plotted the existing data by life-history stage; these different points represent samples and evaluations of the relative survival to various phases through the fish's life. Some work on the Deschutes River system in Oregon, back with the 1975 brood here, gave these stars as data points. The Kalama River study in the lower Columbia gave these open points as data (four different year-classes evaluated in that study). And we have some ongoing work in the Clearwater River system in Idaho that has yielded these preliminary data points. If we take the mean of the data from the Kalama River system, we get a nice smooth curve, as you can see in the lower figure. I think it represents reasonably well the data from the individual year-classes, and shows a continual decline in relative survival throughout the life cycle. In other words, the survival differentiation persists throughout the entire life of a cohort.

We are talking about the survival of the progeny of hatchery fish compared to wild fish, both rearing in natural streams. Please recognize that I'm not telling you that hatchery fish are inferior to wild fish. Rather, I'm telling you that hatchery fish in the natural stream system appear to be inferior to wild fish. In the hatcheries, we have seen the opposite results. I am not here to curse all hatchery fish. I am simply talking about how they probably affect wild populations, and, possibly in that context, I'm doing a bit of cursing.

I have shown you the survival data, the evidence of reduced survival of fish from hatchery populations when they rear in natural streams. I typically interpret such data using these simple spawner-recruit relations. A spawner-recruit relation is the number of adult progeny or the number of returning adults in one generation *versus* the number of spawners (or parents) in the previous generation. And I will define "carrying capacity" as the peak of this spawner-recruit relation, measured in terms of returning adults.

Now, when there is a superimposed or increased mortality reducing survival, as we have seen with these previous data (Fig. l), it's important to know at what stage in the life history this occurs relative to the density-dependent bottleneck in the population. If, for example, a population is limited by spawning area, then the bottleneck, of course, is occurring very early in the life history. And almost all of this differential mortality that we see between hatchery and wild fish would be reflected in the spawner-recruit relation, by reducing carrying capacity as well as productivity. Productivity is reflected by the slope of this curve, and actually is the number of recruits per spawner. If a superimposed mortality occurs before the bottleneck in a natural spawning population, it has no effect on carrying capacity but does reduce the productivity of the population. We will see in a model here at the end that such mortality has important implications, also.

One other way to massage these data -- in fact, the primary way to massage these existing data -- is to try to look at the rate of genetic change; i.e., how fast hatchery programs have changed the hatchery population. So I've taken that same data we looked at earlier and now drawn single points for each study (Fig. 2a). We have relative survival on the Y-axis; survival to yearling on the left axis; survival to adult on the right axis.

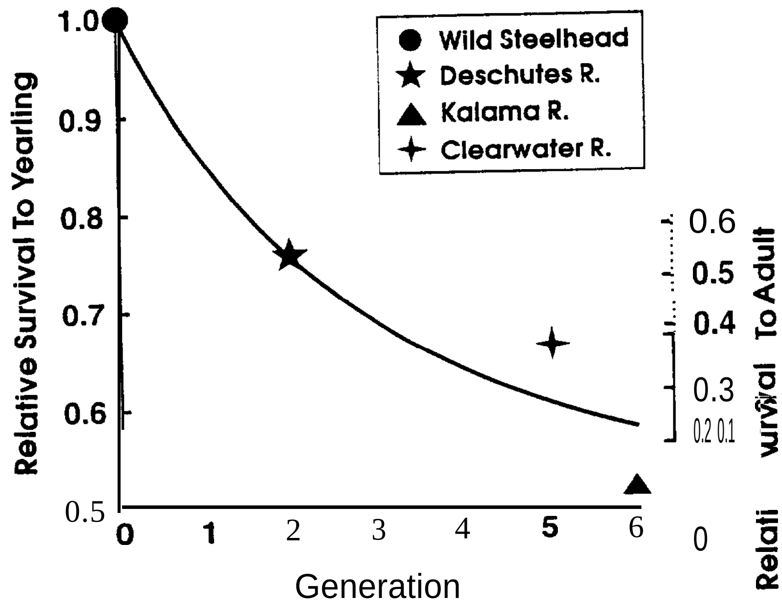

Figure 2a

Survival for offspring of hatchery steelhead relative to that for offspring of wild steelhead vs. number of generations the hatchery populations had been in the hatchery. Hatchery and wild fish reared together in natural streams until termination of the experiment or until migrating to sea. Survival was from the eyed-embryo or swim-up fry stage for Deschutes River fish (stars; Reisenbichler & McIntyre 1977), the swim-up fry stage for Clearwater River fish (crosses; NBS unpubl. data), and unfertilized eggs (prior to being spawned naturally) for Kalama River fish (triangles; Leider et al. 1990. The value for zero generations is 1 by definition.

Only one of the studies went all the way to adult, the Kalama study. But I think this axis is still fairly reasonable for all these studies, although it's only crucial to the Kalama. In generation 0, we are still dealing with wild fish. As I said, the relative survival then would be 1. In the Deschutes study, the hatchery fish had been in the hatchery only two generations; in the Clearwater study, five generations; and in the Kalama study, six generations. So there are other differences between these studies, and they are important differences. But I think the relation that I have drawn here is not unreasonable to expect, and the data suggest it.

So I'm going to proceed on the basis of this relation. The first conclusion I want to draw from this relation is that, as you would almost surely expect, it seems to be an asymptotic relationship, suggesting that no matter how long a hatchery population is in the hatchery, they probably can reproduce naturally, within limits. However, they may well be only 20% as effective at reproducing or surviving in the natural system. So the asymptote is one element I want to stress. The other conclusion is that this relation suggests that, with each generation in the hatchery, the population moves approximately a third of the distance towards this asymptote. Thus, with the first generation in the hatchery, the population moves along this trajectory about a third of the distance to this asymptotic value. With the next generation, the population moves about a third of the remaining distance to the asymptotic value, and so forth. I will use this conclusion in further development, also.

I'm talking about reduction in survival to adult, or carrying capacity. Again, I will talk about a stream system limited by spawning habitats. For a population in the hatchery for more than six generations, I'm saying that the reduction of carrying capacity will be 80% based on the data I've shown you. And if the bottleneck for natural rearing occurs in the first winter, right before the yearling stage of development, then it looks like we would reduce the carrying capacity less, but substantially, to 65 % after six or more generations in the hatchery.

I am now going to talk about a supplementation program where, after the first generation, we take all the wild fish into the hatchery, but only wild fish. So no families of fish are in the hatchery for more than one consecutive generation. So, assuming non-overlapping generations, again for simplicity, we start out with an initial wild population represented by this circle (Fig. 2b). We take, in this case, roughly half the fish into the hatchery and propagate them. We have a good, successful hatchery program, so we have a much higher productivity from the hatchery population. We have a large number of returning adults from the hatchery program. The fish that spawn naturally produce a

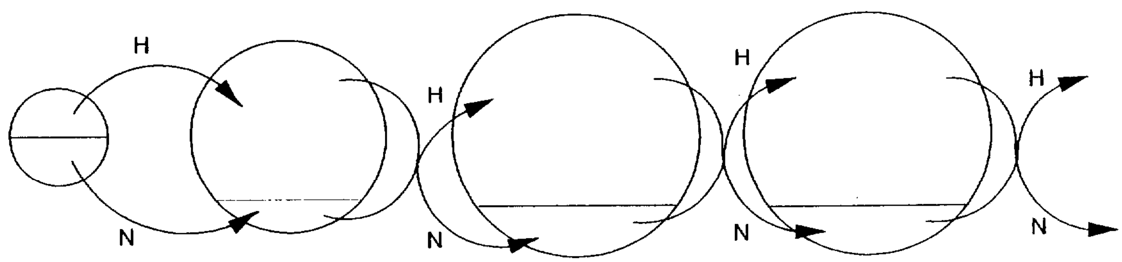

Figure 2b

Diagram of the hypothetical supplementation program considered in this manuscript. Each circle represents one generation of the steelhead population, indicating the expected size and (hatchery/wild) composition at the time of spawning. Initially, the population is entirely wild. One-half of the adults are allowed to spawn naturally (N), and one-half are spawned in the hatchery (H) where their offspring are reared to the smolt stage and then released. In each succeeding generation, all hatchery-reared fish are allowed to spawn naturally and all wild fish are spawned in the hatchery so that the two lineages are identical except that they rear naturally (or in the hatchery) in alternate generations. Total production for each generation after supplementation consists of both hatchery (H) and natural (N) production, and is greater than the original natural production alone.

smaller number of wild fish. The next generation, those wild fish that are brought into the hatchery, produce this larger number of fish. The hatchery fish spawn naturally and produce this smaller number of wild fish and so on, generation after generation.

So what happens? I have told you that I'm going to rely on the previous curve from the existing data which said that, with each generation in the hatchery, the population will move a third of the remaining distance towards the asymptotic value. Here again (Fig. 3) we have relative survival on this Y-axis; generation on the X-axis. In generation 0, we have wild fish whose relative survival 1 by definition. By the way, I'm talking about egg-to-adult survival here. So in the first generation in the hatchery, the fitness for natural rearing declines about a third of the way to the asymptotic value. These fish come back as adults. They are allowed to spawn naturally. Natural selection in the stream system operates on these fish, and my model dictates that natural selection moves them a third of the distance towards the asymptotic value for a wild population, which is a fitness of 1.

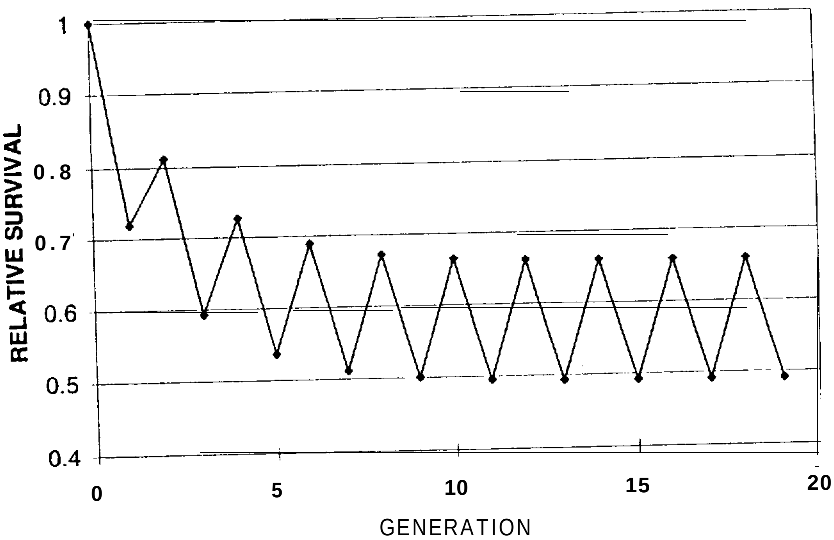

Figure 3
Predicted egg-to-adult survival under natural rearing, relative to that for the initial wild population, for a line of steelhead reared in a conventional hatchery for one generation, spawning naturally and rearing in a stream the next generation, reared in the hatchery the next generation, etc. Relative survival for natural rearing decreases with each generation in the hatchery, and increases with each generation of natural rearing.

So the fitness increases in the second generation. When this generation returns, they are taken into the hatchery; fitness declines. They spawn naturally; fitness increases. Decline, increase, on and on. And pretty soon we reach this near steady state. After about the ninth generation, we are just bouncing around between the same two values between generations.

Now I want to talk, at least initially, about the stream system that's limited by spawning habitat. Almost all of this difference in survival will show up as an effect on the carrying capacity of the system. Here (Fig. 4) I'm talking about the remaining proportion of original carrying capacity, and about generations in the supplementation program. Again, at generation 0 , the population potential is for full carrying capacity. After the first generation, it drops. I am using only odd generations because these fish spawn naturally only after every other generation, immediately after the generation in the hatchery program. So you can see that the carrying capacity in this example -- the carrying capacity dictated by the population and the habitat combined -- drops to one-half the initial level by the ninth generation.

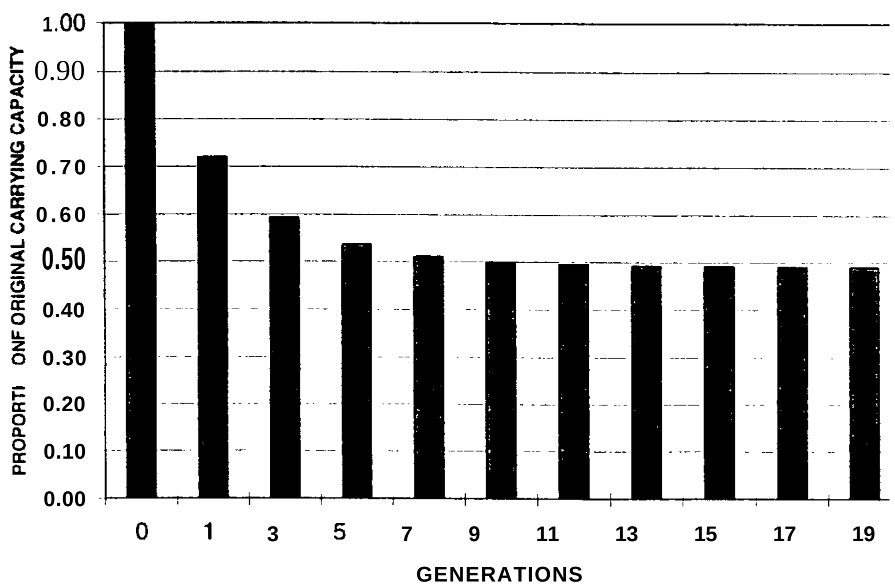

Figure 4

Decline in carrying capacity (and productivity) for a hypothetical steelhead population after supplementation with hatchery fish. Carrying capacity is 1 .0 for the original wild population before supplementation, and is reduced by 500% after nine generations of supplementation. Hatchery rearing begins in generation 1, using only wild fish from the population to be supplemented. Steelhead production for this population is limited by the amount of spawning gravel.

Now, here's the challenge. I hope I can keep you all with me, because this is the key to understanding what I've done. I've said supplementation will reduce the carrying capacity. What does that mean? Again, we're using spawner-recruit relations -- simplified models, ignoring year-to-year variation in environmental conditions, largely for the purpose of illustration. I'm saying that this curve A (Fig. 5) is the original spawner-recruit relation for a naturally spawning population, which was formerly much higher before the hydropower system, before logging, grazing, channelizing, and so forth.

It's what we apparently have now in most parts of the Columbia River system. This diagonal line is the replacement line. On the spawner-recruit model, the equilibrium population size is where the population is not increasing, it's not decreasing; it's simply replacing itself. That occurs where the replacement line intersects the curve.

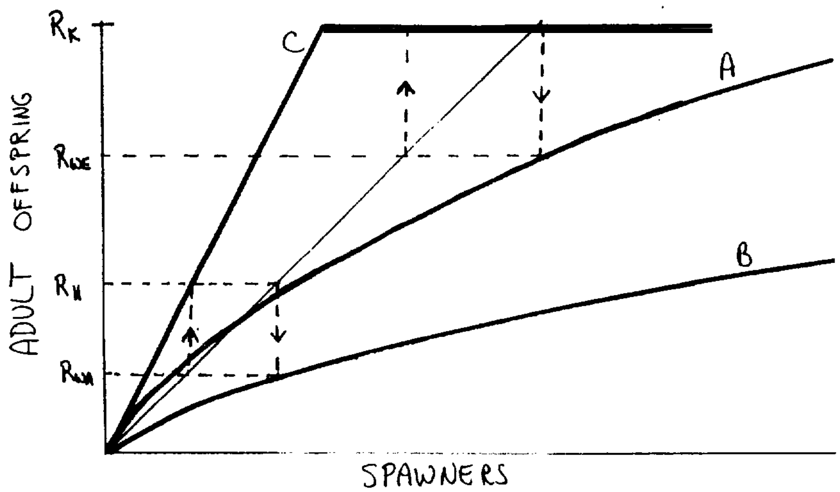

Figure 5

Hypothetical reproductive relations for a naturally spawning population (A) before supplementation, (B) after nine generations of supplementation (when productivity and carrying capacity are reduced by 50%, and (C) for hatchery-reared fish. Diagonal line shows where the number of progeny equals the number of spawners. Except for first generation, all wild fish are used for hatchery broodstock; all hatchery fish are allowed to spawn naturally. RK is the carrying capacity (measured in returning adults) for the naturally spawning population before supplementation, and for the hatchery. Managers ignoring the genetic consequences of supplementation expect total production (natural and hatchery) to be RK + RWE = 1 .7R_K. However, realized production will be RH + RW = 0.55R_K, only one-third the expected level.

So we have a population that is initially hovering at this level. Now we decide to build a hatchery with a reproduction relation like this, a much more productive hatchery than the wild population. You see the slope of this line is substantially greater than for the wild population. And for the purpose of this demonstration, I chose a hatchery that would have a hatchery capacity equivalent to the carrying capacity for the wild population. We can really pump out some fish here. We ought to get some good production. A manager who doesn't consider genetic quality, i.e., the genetic consequences of one of these programs, would expect a total production from this system of R_K, the carrying capacity level, the hatchery capacity, plus RWE , the expected wild recruitment. This box represents the equilibrium position or equilibrium state of this population. This number of spawners produces that number of recruits, who, when they spawn in the hatchery, produces this number of recruits. Going to the replacement line, that number of adults spawning naturally produces this number of recruits. So the population is simply cycling along. We are theoretically getting R_K hatchery production, R_{WE} natural production. That's what we naively expect from the hypothetical supplementation program. But what do we really get?

If, again, the population is limited by spawning habitat, the reproductive relationship for the wild population drops by 50%, thus reducing the carrying capacity and productivity. Here's where we end up for an equilibrium position. Let me go back to this first curve. I will try to make you more of a believer that this is an equilibrium. Let's say we had a lower number of spawners, this number, for example. This number of spawners would produce that number of recruits, which, bouncing off this replacement line, gives this number of recruits (the next generation), again going to the replacement line, bouncing off, puts us right back in this trajectory. So this is a stable equilibrium. The population will move to this position, just as it will move to this other area on curve B.

Playing with curve B is a little messier because there is less space between lines down here. This number of spawners produces that number of recruits, this RWA. Bouncing off the replacement line, RWA spawners produce in the hatchery program RHA recruits, which, when they spawn naturally, produce RWA recruits, and on and on. So the actual total production, what the A signifies, the recruitment from the hatchery plus the actual wild recruitment, is only a third of the sum of RK and R_{WE}, the naively expected values. The typical number of natural spawners is greater than we had with curve A, but the production from natural spawning is substantially less.

In other words, before supplementation we had a natural production level up here, unlabeled. Now I'm saying that the natural production is down here. So should we really call this conservation? This impact is something the manager needs to be aware of. This impact is a very important issue for planning and for conservation purposes. It turns out that this supplementation program would produce far more fish if we forgot about supplementation and simply used the hatchery program to produce hatchery fish while keeping the hatchery fish separate from the wild fish. If we model a population where the density bottleneck occurs shortly before the yearling stage of development, then the modified curve for this natural spawning population doesn't come down quite as far as in this illustrated case. But actual production still ends up to be only half the expected production.

So I think there are some really important issues for managers and other planners to consider here. Before I go on, I want to mention Chuck Peven's (1993) paper describing the supplementation program for steelhead in the upper Columbia River system. He pretty much pronounces the supplementation program a resounding success, and tells us that it's the only reason we still have steelhead up there. The natural steelhead cannot replace themselves anymore. And Chuck's conclusion may well be correct, although part of the reason he was able to do the paper is that the supplementation program has been in existence for a number of generations. Perhaps it is likely that without supplementation, the population up there might be on curve A, able to reproduce itself; whereas with supplementation we have reduced the productivity of the population to curve B, where this population does not intersect the replacement line. The population cannot replace itself; without continued supplementation, it goes extinct. So this illustrates another aspect of supplementation. If we quit supplementing, we may -- in fact, we do -- put the population at risk of extinction unless it can recover fitness fast enough to rise above the replacement line.

In conclusion, I believe the evidence is compelling that supplementation, which is proposed as a primary tool for restoration, will produce far less than expected, may produce far less than would separate hatchery and wild fish programs, and may indeed be a threat to the continued persistence of the wild populations. We need to think more rigorously before we get seriously into supplementation programs.

AUDIENCE: Could you give me your definition of "supplementation" in the context you used it in your talk?

MR. REISENBICHLER: The general definition of "supplementation" is to increase the number of naturally spawning fish with hatchery fish. We usually do that by releasing the hatchery fish out into the natural stream system so that they return and spawn naturally. In this example, we released them out into the system and let them spawn naturally when they return. Meanwhile, somewhere lower in the system we removed the wild fish and brought them to the hatchery program. So my definition differs a bit from the LichatowicWMobrand definition in that they couldn't call this supplementation. Their definition requires maintaining the fitness of the population, I believe. Basically, they're going to increase the number of naturally spawning fish without compromising the fitness of the population. I think I've demonstrated that that's next to impossible. If so, they have nothing to talk about. With my definition, I can talk about supplementation because I haven't put a severe restriction on it.

AUDIENCE: In your measurement there for the Deschutes River and the Kalama, where your theoretical curve dropped to survival to fitness, from what stage did you measure survival between hatchery and natural fish? And was that consistent for all of the population for which you generate that theoretical curve?

MR. REISENBICHLER: There were some differences. The Kalama study was the only one of the three that would have included differences in reproductive behavior. If the adults simply didn't know how to spawn, that would have been a confounding effect As I say, I've pushed the existing data pretty hard. But, indeed, you see that one year these Kalama fish had a higher survival initially, so we know that those fish do know how to spawn. It's not simply a matter of these fish not knowing how to spawn or spawning at completely the wrong time.

AUDIENCE: I was just trying to figure it out. Because to generate that theoretical curve, which is the basis of your whole thesis, it seems there are examples that are inconsistent with that. For instance, if you look at south or north Umpqua River steelhead in Oregon, that program has been in place since the 1950s. And I think for first-generation wild fish, it doesn't appear there is any reduction in spawner-recruit ratios.

MR. REISENBICHLER: How good are the data for evaluating that pristine spawner-recruit relation and the current one for natural production?

AUDIENCE: Same problem with what you have that generates these basic curves. The whole premise is based on this theoretical curve and the difference between a one-third reduction and no reduction in that first generation, the change in your perspective in how you deal with supplementation, as you move along your axis out to six generations. I think there is not a lot of argument. But in the beginning, where that lies is going to be very sensitive to management.

MR. REISENBICHLER: I do agree with you that I have not presented the last word. I am pushing the data. Nevertheless, I think I have made a very defensible and reasonable interpretation of that data. But we need more data. However, if you agree with the asymptotic values and you agree that we get there by six generations, or approximately that, then it seems to me you are hard-pressed to argue with what happens in the first generation. Certainly, the rate of change is going to decrease. And this asymptotic curve is the only reasonable type of relation to expect. So it might be a 25% change, or perhaps a 50% move towards that asymptotic value per generation; but the data indicate a substantial shift in survival or fitness in only one generation. Otherwise, in this study we couldn't have seen differences after only two generations in the hatchery. Sure, a few people would argue that all the shift occurred in the second generation and none in the first. But it's like breeding milk cows when I was on the farm: I start my herd with a bunch of mediocre cows, and I get my biggest improvement in milk production the first generation of using quality bulls, then a smaller improvement in the second generation. By the fifth generation, I'm just sort of treading water and maintaining a good herd. I'm not really getting good improvement anymore. I think that's what we are dealing with here, a straight-forward quantitative genetic trait.

AUDIENCE: What occurs on the left side of that axis has a lot of implication for supplementation which depends largely on what happens in the first and second generations. Basically very limited data can change with what you do.

MR. REISENBICHLER: I guess I think a responsible manager will go with what data we do have while recognizing those limitations. I think we need to do a lot more work with this kind of modeling, including natural variation and other factors. But it seems to me very compelling, especially to the extent that we're charged with conservation. We can't just ignore the existing data because it doesn't really meet --

AUDIENCE: Your Kalama data stopped at 1982 (unintelligible). Do you have more data available now?

MR. REISENBICHLER: Yes. They tell me that they are working with winter steelhead now. The "word of mouth" I got is that they are seeing data very comparable to what they got before. That was the extent of the detail I got from them. There is one more study in the mill with winter steelhead in the Kalama system.

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The scientific basis for estuarine carrying capacity

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Compared to the historic development of the science on Pacific salmon, the concept of estuaries as limited habitats for salmon production is a relatively recent path of investigation. This discussion has focused primarily on salmonid early life history; except in extreme situations (e.g., significantly degraded water quality), adult salmon passage through estuaries to spawn in freshwater is not affected by estuarine conditions. Initially, estuaries were viewed largely as “sinks” in the abrupt transition from natal freshwater habitats to marine waters, explained by the vulnerability of juvenile salmon to predation (Parker 1962). More recently, estuaries tend to be viewed as opportune nursery and rearing systems that can provide migrating salmon a margin on oceanic survival by providing habitats for opportune foraging and growth potential in relative protection from predation (Healey 1982, 1991). However, the imposition of man throughout the salmonid life history has modified many of the dependent relationships of salmon in estuaries, which is epitomized by the Columbia River. Both natural and anthropogenic conditions, and potentially the interaction of both, have prompted estuaries to be considered as a major, if not the, bottleneck in Pacific salmon life histories.

Thus, investigating the issue of whether the Columbia River Estuary is limited in its ability to support juvenile salmon demands a comparison of how carrying capacity may have varied naturally before man’s impositions and how it varies now, i.e., under modem levels of depressed salmon populations, alteration of the Columbia River and estuary, and hatchery manipulations. It follows that identifying critical independent factors must address both evolutionary forces shaping salmon life histories and the abiotic conditions that shape estuaries. Understanding mechanisms of change to the structure and fundamental ecosystem processes of the Columbia River Estuary must, in addition, be viewed from the standpoint of their interface with salmon.

Over a variety of historic definitions, carrying capacity has generally been defined as a maximal population threshold given resource constraints, and classically represented by the asymptote of the logistic (population) curve (Pulliam & Haddad 1994). The fisheries science application of this concept would translate to a definition of estuarine carrying capacity as “the maximum number (production) of juvenile salmon that can be supported in the estuary at any one time.” The implication that this is an instantaneous function, however, is erroneous because the ecological and, to a lesser extent, physicochemical relationships that affect fish production are prolonged, often lagged, and consequently non-linear. Carrying capacity (1) is a function of density-dependent, environmental factors; (2) is the compounded effect of both mortality and growth within the estuary; (3) varies as a function of species, race and life-history type (tactical) composition of salmon populations; and (4) differs by type (e.g., hydroperiod, circulation, energy) of estuary and distribution and structure of estuarine habitats.

Estuarine passage can be a site for strong natural selection. Evolution alone would argue that, averaged over the life spans of salmon, estuaries would be a source of salmon production, not a sink. Pacific salmon populations, with their relatively long numerical response times, have evolved diverse life-history strategies (species, types, races, tactics) to compensate for environmental variation across time- and space-“scapes” throughout their entire life cycle. Over evolutionary time, salmon will tend to average over high-frequency (short time and space scales, e.g., freshwater-estuarine-marine; interannual) components of environmental variation, and to track low-frequency (long time-scale, e.g., decadal, ocean regime shifts) components.

Life-history diversity varies considerably among the species of Pacific salmon, from almost monotypic pink salmon, with essentially no freshwater residence and only one year of ocean rearing, to chinook salmon that may or may not rear for various periods of time in freshwater before migrating through estuaries at differing rates before rearing in the North Pacific Ocean for various periods. The extreme case of chinook salmon life-history diversity is well illustrated by Healey (199 l) who designated two racial (“stream” vs. “ocean”) and 4-5 tactical differences. Under certain circumstances, estuarine carrying capacity has likely played a large role in the level of diversification of these life-history “strategies.” That selection of any one specific life- history strategy is amply (and, I will add, unappreciably) illustrated by Reimers’ (1973) precise documentation of the respective survival to return (as adult spawners) of five different life-history “types” of chinook salmon in the Sixes River watershed. Comparative scale analysis of outmigrating and returning adults of these five life-history types, including four “ocean” type and one “stream” type, indicated that >90% of the survivors originated from “ocean” type fish that immediately emigrated as fingerlings from freshwater but resided over the longest period of time in the estuary. In fact, despite the potential effect of carrying capacity limitations in the estuary (i.e., reduced freshwater habitat with decreasing summer flows), the fish that persisted in the estuary had the highest survival.

A logical indicator of estuarine carrying capacity is the total residence time in the estuary, with the null model being the higher the residence time the higher the survival. While there may be valid arguments that estuarine residence time may be genetically based, herein I argue that it is more likely to be a stochastic product of both abiotic and biotic conditions in the estuary. Some of the more important biotic conditions include (1) river flow, (2) stage of tide (with particular emphasis on stage of tidal monthly cycle), and (3) turbidity. Biotic conditions include (1) condition or “status” upon entering the estuary (i.e., size, state of smoltification, physiological condition, stamina, reserves),(2) availability of preferred prey (e.g., species, size, distribution, (3) predation, and (4) interspecific competition. In many respects that is not entirely stochastic, but instead may be viewed as strictly a problem in thermodynamics: estuarine residence time is simply the net product of the energy gained by foraging on preferred prey species balanced by the costs of foraging and migrating (Wissmar & Simenstad 1988). This is somewhat of a "circular" model because we still don't know whether the migration rate (e.g., swimming costs) are independent or dependent on frequency of prey encounter or foraging success.

Unfortunately, while the Columbia River is perhaps one of the best documented salmonid ecosystems in the world from the standpoint of adult returns, we actually know relatively little about the early life history of Columbia River salmon stocks during their residence and passage through the estuary. Since the phenomenally insightful data of Rich (1920), one of the only few strong data sets detailing average migration rates (i.e., the mean of individual migration rates over the sum of a discrete tagged lot sampled) for Columbia River salmon is that of the NOAA-NMFS Columbia River Estuary Data Development Program (CREDDP) (Simenstad et al. 1990b) and associated research in 1978-1980 (Bottom et al. 1984). This is one of the few, if not the only, data sets in which the average rate of migration downriver from various hatchery release points to Jones Beach (RM 45) can be compared to their subsequent passage through the estuary to McGowan (RM 10). Although rates vary over the three years, differences between the river migration and estuarine migration rates are consistent with the current life-history model: larger juveniles (smolts) migrate much faster and have lower estuarine residence times than subyearling fry and fingerlings. Steelhead actually migrate faster through the estuary (avg. 43.5 km/d) than downriver (27.3 km/d); coho smolt migration rates are slower but similarly more rapid through the estuary (25.3 km/d) than downriver (18 km/d); chinook yearlings generally slow down somewhat or have equivalent migration rates between downriver (20 km/d) and the estuary (19.3 km/d) but chinook subyearlings generally (except in 1980) migrated significantly slower through the estuary (13.3 km/d) than downriver (18.7 km/d). In some years (1978-1988) there was as much as a 1 O-12 km/d differential between the river and estuary migration rates; the 1980 rate may have been exceedingly biased by the eruption of Mt. St. Helens (Emmett et al. 1990).

The question of whether the fundamental structure and processes supporting juvenile salmon in the estuary have been altered by anthropogenic changes to the Columbia River ecosystem can be inferred, although not resolved, by several lines of evidence. If production and availability of prey could limit juvenile salmonid foraging success under some circumstances, changes in the habitats that are the source of this production and feeding could logically affect carrying capacity. In fact, the habitat structure of the estuary has changed dramatically since 1870, with much of these changes occurring before substantial modifications were made in upriver ecosystems. By 1970, the area of estuarine tidal swamps had decreased by 77%, tidal marshes by 62%, and open water by 1 l%, due principally to diking, filling and dredging; shallows and flats increased by 7%, due primarily to natural accretion and some filling (Thomas 1983). Such extensive loss of estuarine swamp and marsh habitat would likely impact subyearling (fry and fingerling) utilization of the estuary more than yearling smolt utilization.

However, changes upriver have also fundamentally altered the estuarine food web in several ways that might affect carrying capacity of juvenile salmonids. For example, comparison of pre- 1870 and modern (1980) conceptualized food-web structures indicate that the sources of organic matter contributing to higher level consumer (e.g., fish) production may have shifted significantly from macrophytic (emergent swamp and marsh plant) detritus generated in the estuary to microphytic phytoplankton detritus generated in upstream reservoirs (Simenstad et al. 1990a, Sherwood et al. 1990). In addition, modification of river flow (i.e., dampening of high- and low-flow cycles) may also have reinforced the food-web components and processes associated with the estuarine turbidity maxima (ETM) in the estuary (Simenstad et al. 1993). It is impossible to say, however, whether this could have affected the production of preferred prey of juvenile salmon to the extend that it has become limiting. Some components (e.g., ETM zooplankton-supporting mysids, sand shrimp, baitfish, Pacific tomcod, and marine mammals) may have become enhanced due to the ETM microdetritus-based food-web pathways, but these pathways may also contribute to planktivorous salmon (e.g., yearling chinook, coho) (Craddock et al. 1976, Durkin 1982).

The introduction of exotic species may also have altered estuarine communities and processes in several ways that affect juvenile salmon carrying capacity. For example:

1. The introduction of American shad, *Alosa sapidissima*, may pose competition for some food resources, but their spatial overlap with salmon does not usually translate into overlap in diet when in the estuary, except perhaps during the winter in lower river/tidal fluvial habitats.

2. Establishment of an exotic (Asian) copepod, *Pseudodiaptomus inopinus* (Cordell et al. 1993), may actually constitute a supplemental prey resource but could also represent a potential competitor to the important indigenous copepod, *Eurytemora affinis*, that is exceedingly important to the estuarine food web (Simenstad et al. 1990).

3. A widely distributed exotic clam, *Corbicula manilensis*, could potentially reduce phytoplankton standing stock in the freshwater-tidal portion of the estuary if their populations became large enough.

4. The common carp, *Cyprinis carpio*, although well established in the lower river-upper estuary, does not likely compete with or prey on salmon.

5. Nutria, *Myocaster coypus*, represents an important herbivore in emergent marshes, but it is doubtful that their consumption of marsh production is significant (Small et al. 1990, Simenstad et al. 1990).

Thus, although definitive evidence is lacking for significant effects from exotic species, the potential for an effect cannot be discounted.

Universally, we lack substantive evidence on estuarine carrying capacity limitations. Even basic information is lacking, such as the distribution and behavior of the more estuarine-dependent species, races and life-history types. While there is some indirect evidence of increased survival due to estuarine residence for a few estuaries (e.g., the Campbell River; Macdonald et al. 1988, Levings et al. 1989), we do not understand how universal these relationships are, whether subsequent density-dependent compensatory effects occur in the ocean, or whether the strength of the underlying mechanisms changes with large-scale changes, such as oceanic regime shifts. Another unknown is the variability of life-history types (tactics), and the variability in survival value of each type. Correspondingly, how each life-history type responds to freshwater and estuarine conditions is suggested by only a few studies (e.g., Reimers 1973; Healey 1979, 1980; Sibert 1979); it is particularly important to understand whether the timing and cues to estuarine entry are genetically-based or linked to more stochastic conditions in both freshwater and the estuary.

Information gaps are particularly conspicuous in the case of the Columbia River estuary, where basic data are poorly known, if at all. These include (1) fry and subyearling habitat distribution, migration rates, residence time and ecology; (2) prey distribution, prediction and availability (especially for peripheral habitats and for insects); and (3) competition and predation effects of exotic species. An important point to remember is that the little information available on juvenile salmon migration, residence, and ecology in the Columbia River Estuary is based predominantly on large fingerling and smolts from hatcheries (e.g., those that are most easily tagged), which are the races and life-history types that are least likely to utilize the estuary or be limited in their ability to do so! These basic data can only be obtained by comprehensive field investigations in the estuary, stratified by the various habitats available for migration and rearing, and linked integrally with studies of prey and predator distributions and functional responses to the salmon populations. Ultimately, more extensive research will be required to test the validity, variability, functional relationships, and mechanisms of carrying capacity by using controlled manipulative experiments and/or taking advantage of “natural experiments,” incorporating tagging or analogous (e.g., otolith microstructure analyses) of all potential races and life-history types.

Another viable approach might be to conduct retrospective analyses of changes in stock composition relative to changes in the estuarine ecosystem and exogenous (e.g., ocean regime shift) effects. Such analyses might, for example, contrast migration rates and residence times relative to life-history composition of lower Columbia with upper Columbia River stocks. Modeling would also be a potentially productive approach to evaluating the bioenergetic bases of estuarine carrying capacity, especially for assessing the predict-ability of functional responses (e.g., residence time) relative to estuarine conditions (e.g., river flow, prey resources). Model predictions, as well as non-modeled factors (e.g., effects of hatchery production), would have to be tested by manipulation of hatchery releases (including tagged fry and small fingerlings) and compared to the performance of native stocks migrating through and rearing in the estuary at the same time.

If there is a summary statement about evaluating the carrying capacity of the Columbia River Estuary for juvenile salmon, it is that we presently do not have the appropriate information to make that assessment. In fact, the considerable data that have been gathered on juvenile salmon migration through the Columbia River system generally cannot be applied to any aspect of the role of the estuary at the final transition into North Pacific waters. Furthermore, the data that do exist by and large arc extremely biased against those life-history types and species likely to utilize the estuary for rearing and that potentially accrue increased survival to return as a result. While the evolutionary development of Pacific salmon species, races, and types implies a strong selective role of the estuarine residence, it is difficult and impossible without a distinctly new approach to Columbia River salmon research to determine the role of the estuary, much less assess whether estuarine carrying capacity is limiting salmon production.

- **Is the ability of the Columbia River estuary to support juvenile Pacific salmon limited?**
  - **Did it vary naturally (historically)?**
  - **Does it vary under modern levels of depressed salmon populations, alteration of the Columbia River and estuary, and hatchery manipulations?**
- **Likely determinants of estuarine carrying capacity**
  - **biotic;**
    - **» species/race/tactical variation in estuarine rearing**
    - **» intraspecific density-dependent factors**
    - **» interspecific interactions**
  - **abiotic;**
    - **» river flow and estuarine circulation**
- **Changes to ecosystem and salmon that potentially affect carrying capacity**
  - **prey resource composition and availability**
  - **juvenile salmon composition and demography**

Figure 1
Scientific basis of estuarine carrying capacity.

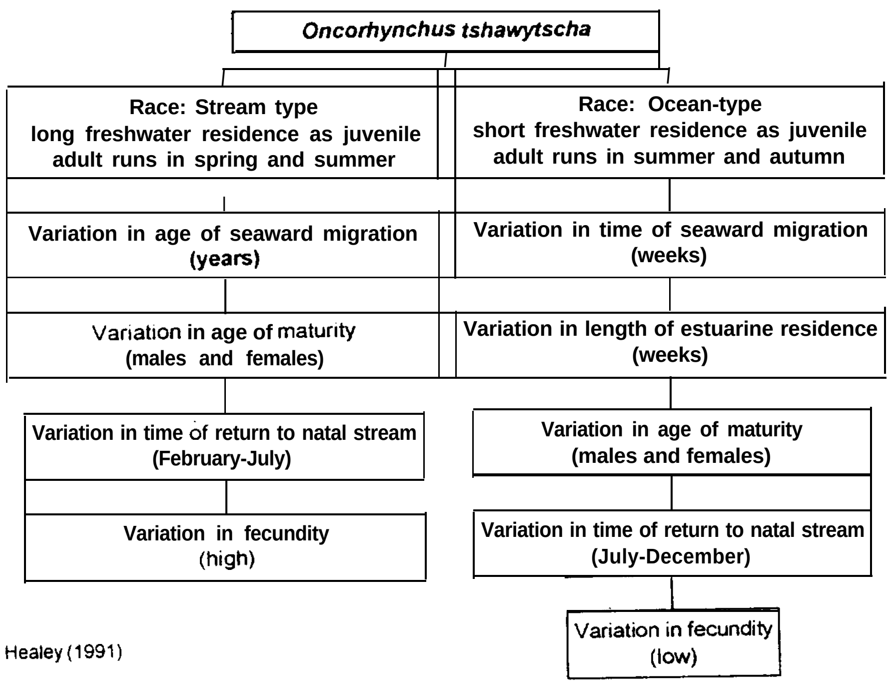
maximum number *(production) of juvenile salmon that can be supported in* estuary at *any one time*

- **function of density-dependent, environmental factors**
- **compounded effect of both mortality and growth within the estuary**
- **varies as function of species, race and life history type (tactical) composition of salmon populations**
- **differs by type (e.g., hydroperiod, circulation, energy) of estuary and distribution and structure of estuarine habitats**

Figure 2
Estuarine carrying capacity for juvenile salmon.

- estuarine passage can be a site for strong natural selection; under most circumstances, would expect it to be a source for salmon production, not a sink
- Pacific salmon populations, with their relatively long numerical response times, have evolved diverse life history strategies (types, races, tactical) to compensate for environmental variation across time and space scales through their entire life cycle
- will tend to average over high frequency (short time and space scales, e.g., freshwater-estuarine-marine; interannual) components of environmental variation, and to track low frequency (long time scale, e.g., decadal+, oceanic regime shifts) components

Figure 3
Evolution of Pacific salmon estuarine rearing strategies.



Modified from Healey (1991)

Figure 4
Life-history structure of chinook salmon.

Life History Characteristic	Life History Type				
	Type 1	Type 2	Type 3	Type 4	Type 5
Freshwater Rearing	no	yes	yes	yes	yes
Freshwater Rearing Habitat	--	mainstem, tribs	mainstem, tribs	tribs	mainstem, tribs
Fish Leaving Freshwater	fry	fingerlings	fingerlings	fingerlings	yearlings
Length of Estuarine Residence	none	extensive	extensive	sbort	short
% Returning to Spawn	0	2.5	90.7	3.7	3.1

Figure 5
Tactical types of freshwater and estuarine rearing by juvenile chinook salmon in Sixes River (Reimers 1973).

- **river conditions**
  - flow
  - stage of tidal month
  - turbidity
- **condition upon entering estuary**
  - size
  - smoltification
  - physiological condition, stamina, reserves
- **preferred prey availability**
  - species
  - size
  - distribution
- **predation (real and perceived)**
- **interspecific competition**

Figure 6
Estuarine residence : carrying capacity. Functional response to multiple, and interacting, biotic and abiotic factors.

- scope for growth (G) is balance between net energy intake (I/t) and combined costs of standard metabolism (T_s) and migration swimming cost (T_m),

$$G = I/t - (T_s + T_m)$$

- net energy intake (I/t) is a function of individual prey encounter rate (Y), assimilated fraction of prey ingested (A), the caloric value of the prey (*i*), and the energetic cost (T_f) and handling time (H) to pursue and consume the prey,

$$I/t = Y\,(Ai - T_f H)\,/\,(1 + YH)$$

- still somewhat "circular" model because we don't know whether migration rate (e.g., swimming cost) is independent or dependent of frequency of prey encounter or foraging success

Based on juvenile chum salmon; Wissmar and Simenstad (1988)

Figure 7
Bioenergetic regulation of juvenile salmon estuarine carrying capacity.

	1978		1979		1980	
SPECIES	To Estuary	Through Estuary	To Estuary	Through Estuary	To Estuary	Through Estuary
0+ Chinook	16	4	21	11	19	25
1+ Chinook	20	15	17	15	23	28
Coho	16	26	20	22	18	28
Steelhead	2 1	44	32	--	29	43

Figure 8
Average migration rates of juvenile salmonids, 1978-l 980.

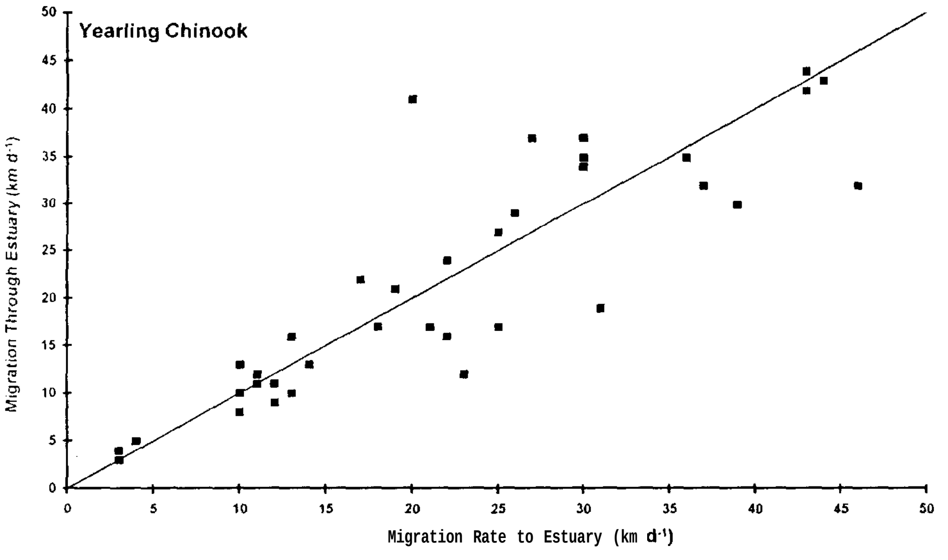


Figure 9
Riverine-estuarine migration rate of yearling chinook salmon, 1978-l 980.

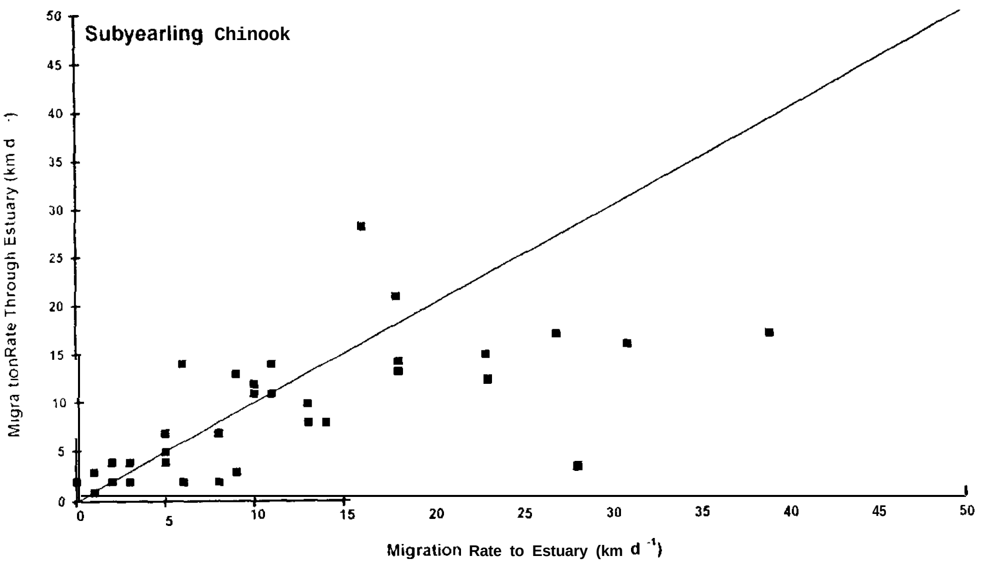


Figure 10
Riverine-estuarine migration rate of subyearling chinook salmon, 1978-1980.

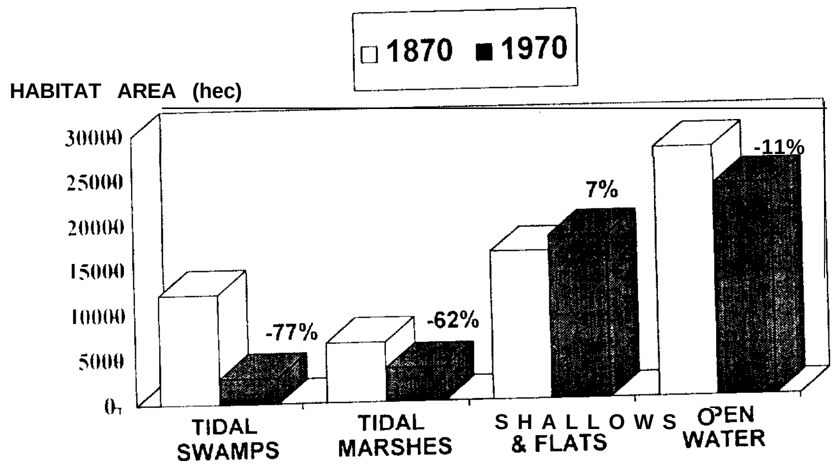


Figure 11
Estuarine habitat changes in the Columbia River Estuary, 1870-1970.

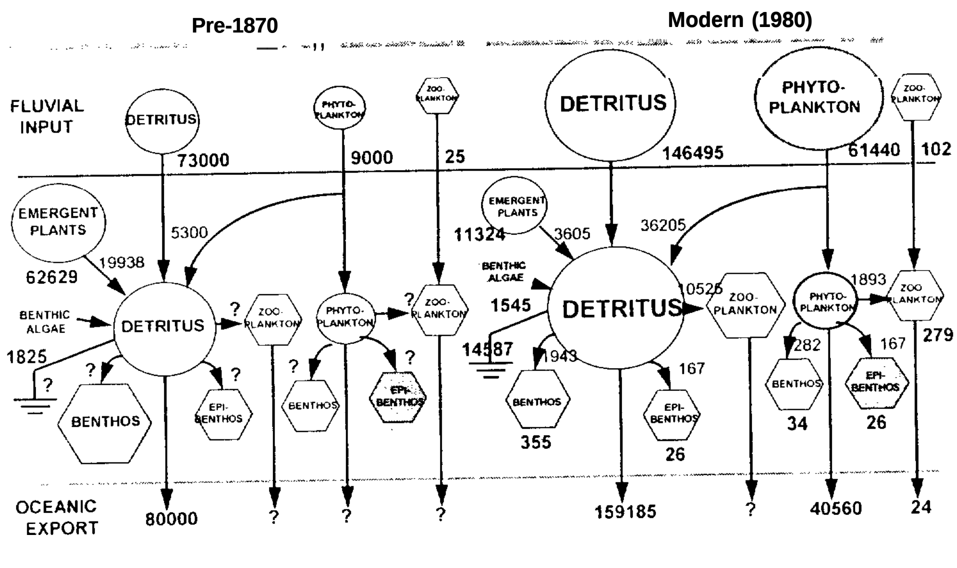


Figure 12
Historic and modern food webs of the Columbia River Estuary.

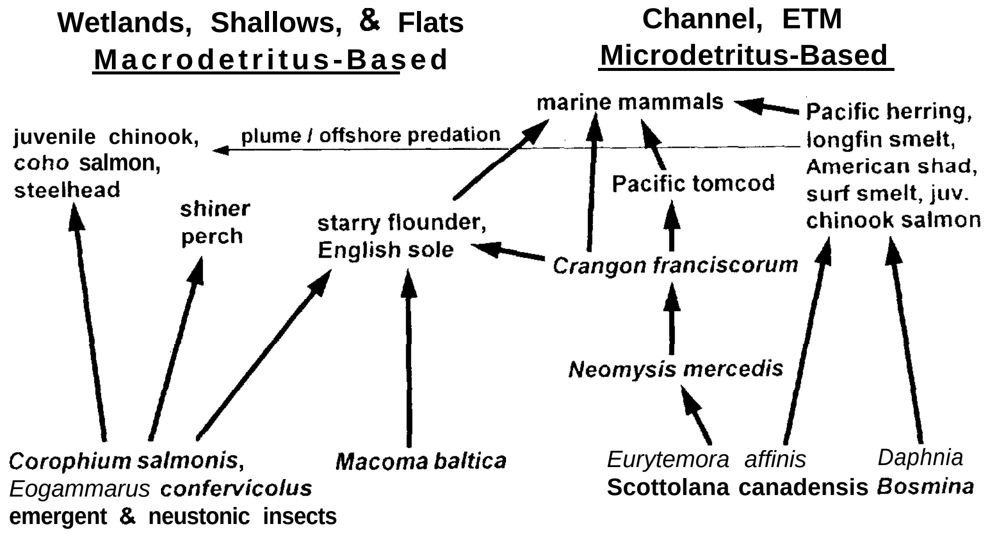


Figure 13
Alternate estuarine food webs of the Columbia River. Based principally on Bottom & Jones (1990), Simenstad et al. (1990), Craddock et al. (1976), and Durkin (1982).

- **American shad *(Alosa sapidissima)***
  - **overlap spatially but comparatively little diet overlap in estuary (winter), potentially in lower river/tidal-fluvial habitats?**
- ***Pseudodiaptomus inopinus***
  - **potential prey resource?**
  - **competitor of *Eurytemora affinis* or other preferred prey?**
- **common carp (*Cyprinis carpio*)**
  - **no predation/competition interference?**
- **nutria *(Myocastor coypus)***
  - **reduced marsh production?**
- ***Corbicula manilensis***
  - **reduced phytoplankton standing stock?**
  - **predation on other (salmon prey) zooplankton larvae?**

Figure 14
Potential effects of exotic species on Columbia River estuarine carrying capacity for juvenile salmon.

- distribution and behavior of most estuarine-dependent species, races and types
- net effects of carrying capacity limitations
  - -indirect evidence (e.g., Macdonald, Levings, et al. experiments in Campbell River estuary
  - -density-dependent compensatory mechanisms, lags
  - -stochastic events, influences of oceanic regime shifts
- genetically hard-wired vs. dynamic freshwater/ estuarine rearing
  - – minor evidence (e.g., Reimers 1973 in Sixes River estuary, HealeylSibert 1979 in Nanaimo River estuary

Figure 15
Universal unknowns.

- fry and subyearling habitat distribution, residence time and ecology
- relative prey availability, particularly for peripheral habitats and for insects
- competition/predation influences of exotic species

Figure 16
Information gaps on estuarine rearing ofjuvenile salmon in the Columbia River Estuary.

- fill in (major) gaps in fundamental knowledge in estuarine salmon life history and ecology
- determine whether carrying capacity is real; analytically <u>and</u> experimentally
- estimate under what conditions there may be a carrying capacity effect
- evaluate role of hydropower operation and hatchery production strategies as limiting factors
- evaluate potential to mitigate carrying capacity limitations

Figure 17
Objectives for estuarine carrying capacity work.

- **Acquire fundamental knowledge:**
  - stocks with particularly large components of estuarine-dependent races and tactical life history types
  - migration patterns and rates of estuarine-dependent species, races and tactical life history types
  - foraging behavior in tidal freshwater and peripheral bay habitats
  - production dynamics and availability of preferred prey resources
- **Conduct retrospective analyses of changes in stock composition relative to changes in estuarine ecosystem and exogenous (e.g., ocean regime shifts) effects**
  - contrast lower Columbia with upper Columbia populations
  - explore interactions between potential estuarine and ocean conditions
- **Model functional response of migrating salmon to estuarine conditions**
- **Conduct manipulative experiments to test model predictions**

Figure 18
Estuarine carrying capacity research to improve salmon survival.

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Chinook salmon populations that spawn and rear in upstream reaches of tributaries of the upper Columbia River: Research questions

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Most of the recommended research questions are discussed using examples for spring chinook salmon and habitats of the Chewuch River (USDA Forest Service 1994, Hubble & Sexauer n.d.). The Chewuch River is an up-stream tributary to the Methow River which is located in the upper Columbia River Basin.

Spring chinook salmon is a stream-type life-history variant. Stream-type life histories occur in inland rivers where populations spawn in upper reaches which are long distances from the sea. The adult spawning migrations occur in spring and summer. Juvenile outmigration to the sea is usually during the spring of their second year (Healey 1991).

Research questions

1. What human actions have impacted salmon habitats since the arrival of European man?

2. What are the habitat recovery times in relation to disturbance frequencies?

3. What are the recovery times for juvenile fish populations in relation to disturbance frequencies?

4. What are the differences between current and historic intrapopulation life-history diversity and the complexity and connectivity of habitats? (Lichatowich et al. 1995).

5. Do variations in the local population's life-history patterns appear to be suppressed by unhealthy habitat conditions? For example, how are the number and distribution of redds and the survival of eggs to fry influenced by habitat conditions?

6. Do the juveniles show variation in migration and rearing distribution within tributaries, between tributaries, and the mainstem of the larger river? For example, what proportions of the parr and smolt populations rear in the Chewuch River versus the main channels of the Methow River?

7. Do the seasonal migration times that are keyed to flow conditions of tributaries (Chewuch) and main river channels (Methow) coincide with adequate discharge levels for fish migration and transport downstream to the Columbia River?

8. Do variations in the migration timing of local populations show responses to variability in growth opportunity (abundant forage), distribution of habitat refugia (cool temperatures), cover, and stress related to predators?

9. What would be a realistic range for the survival rates of Parr?

10. How important are predator-prey interactions in the evaluation of the river's potential carrying capacity for juvenile chinook salmon?

Comment: Predatory-prey interactions and juvenile salmon carrying capacity

Predator-prey interactions during salmon residence and migration between habitats have significance in almost all the emerging issues to be considered in evaluation of the carrying capacities of the various habitats used by Columbia River salmon. Common predators in the upper reaches of tributaries of the upper Columbia River can include bull trout, other salmonids such as cutthroat trout, and birds. In some downstream waters of large subbasins of the mid-Columbia River (e.g., Yakima River), smallmouth bass, catfish, and gulls can cause heavy predation (Lichatowich et al. 1995). Fish losses can coincide with unfavorable periods of low and high water temperatures associated with water diversions.

For tributaries of the upper Columbia River, minimal information is available about predator-prey interactions during salmon residence and migration between rearing habitats. Different age-classes ("sizes") of juvenile salmon require rearing habitats that are distributed through river basins. Habitat preferences of specific size-classes are influenced by numerous biotic and physical factors that change seasonally and over longer periods of time (Wissmar In press). Degradation and loss of any of these habitats imply that the ultimate smolt production can be limited by the least number of a fish size-class surviving limited habitats ("bottlenecks").

Habitat "bottlenecks" may increase predation pressure. For example, a combined "habitat-predator bottleneck" that exists during the late-summer and fall, when decreases in habitat carrying capacity (e.g., less forage, dewatering, and crowding of fish), could increase fish susceptibility to predation. Both carrying capacity and mortality constraints in late summer to late fall can force juveniles to shift to downstream-winter habitats where spatial conditions, food availability, and warmer temperatures may improve fish growth. Fish moving between summer and winter habitats may also encounter "predation bottlenecks" in shallow side-channels (e.g., birds) and deep pools (e.g., large trout). For example, Alexander (1979) noted that great blue herons and large brown trout were the major predators on brook trout in a stream. Herons took the large size-classes of brook trout prey in shallow waters, while brown trout (>30 cm) took large numbers of small brook trout at varying depths.

Summary

Restoration programs for threatened and endangered fish stocks (e.g., sockeye and spring chinook salmon) need to incorporate projects that assess the basic limiting factors to fish production in different habitats. Considerable research needs to be focused on two life stages: spawning adults and juveniles. These life stages, their habits, related carrying-capacity requirements, and predator-prey interactions are critical links to increasing the size of salmon runs in river systems of the upper Columbia Basin. Research projects on adult fish should include evaluation of cover, thermal refuges, and habitat requirements of prespawning salmon and incorporation of this information into management plans. Research projects on juvenile fish need to define the potential carrying capacity, production, and mortality of different age-classes of fish and the influences of the addition of hatchery fish. A major question is the potential impact of hatchery supplementation fish on wild fish.

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Chapter 4: TRANSCRIPT OF THE QUESTION AND ANSWER SESSION

On Day 2 of the workshop, the panelists discussed questions organized around key themes:

- scientific basis for carrying capacity,
- objectives for carrying capacity research, and
- specific research needs.

The discussion concluded with a recommendation to the Council from each panelist on how to most effectively address carrying capacity through both research and management actions. Our original objective for this information was to provide the reader with a synopsis of these discussions and an edited transcript of the question and answer session. However, we were struck by how non-linear the discussion was, in spite of the excellent job the facilitator and panelists did in focusing on the questions. We feel this is a perfect illustration of the limitations of transforming the dialogic exploration of a tremendously broad subject like carrying capacity into a condensed written text. We were frustrated in our attempts to paraphrase the dynamics of the discussion and also capture the density of the subject matter. Our condensation read like a simplification, even a distortion, of the rich and dense discussion.

The following pages are the partially edited transcript of the question and answer session as recorded during the second day of the workshop. To help the reader, we have cataloged the many discussion points according to key subject areas and speakers. The key areas, with pages numbers are listed below.

Subject and Author Index of Day-2 Question and Answer Session

Day-2 Introduction

MR. NEITZEL: Good morning. Today we will go through the set of questions for our panel that's on the third and fourth pages of the agenda. The first set of questions deals with the scientific basis for carrying capacity, that is, to try to find the definition or definitions. After yesterday, I'm sure it's "definitions" and not "definition." But more importantly than the panel's definition, we want to know their scientific framework. What's the hypothesis that underlies their definition? And could they explain that to a layperson? Following up on the definitions and hypotheses, we will ask about the determinants of carrying capacity, giving examples of biotic and abiotic determinants that make them limiting. And then how do these determinants affect survival of salmonids?

The second set of questions relates to objectives for carrying-capacity work. If you as a panel were to design a carrying-capacity study program for the Columbia River

Basin, what would your objectives be? In other words, what would you want from carrying capacity research? If you or someone else were to conduct this research, what would you want to have in your hand when it was finished? And then, given your definition of carrying capacity and the work that you've talked about, what would stand in the way of meeting those objectives3 In other words, what are the critical uncertainties associated with your research needs?

Then we will go on to the research needs. What specifically do we have to do? What can we do now and what should be done first? And then on to management actions. What can fisheries managers do, now and in the long term, relative to carrying capacity and salmon survival? And, finally, what determinants of carrying capacity can we monitor to evaluate these management actions?

Those, then, are the three sets of questions. And I'd like you to direct your comments on these questions to the Power Planning Council. At the end of the day, you will have a chance to say, "This is what I think you need to do. This is what should be in your carrying capacity study plan."

Scientific Basis of Carrying Capacity

DR. COUTANT: I was struck by the contrast in the presentations yesterday. At one extreme was the attention to detail in looking at a particular portion of carrying capacity, as in my presentation; the other extreme was to look at aggregate carrying capacity, at deforestation and logging and siltation, the catalog of things that have happened in the Basin to reduce salmon productivity. I'm not in any sense saying one is right or wrong, but I was struck by the contrasting ways that we are all looking at carrying capacity. And I, for sake of discussion, argue that it makes more sense to look at it in detail, because then we can get at the question you have here about providing a scientific framework for the definition.

And in the context of what Lars Mobrand was talking about, we have a hierarchy of things going on out there. We have lots of populations, an awful lot of stuff going on out there to try to figure out in any sensible aggregate way. But if you think of each of these populations as going from one place to another and evolutionarily tapping, to the best of their ability, the resources as they go -- tapping the ability to spawn, the ability to rear, to migrate, to feed along the way, and to get through the estuary and out into the ocean -- at each of these stages, they have to maximize their ability to produce numbers, produce biomass. And you can zero in on a few of those and try to do a detailed job of asking, what is the carrying capacity at this stretch for this life stage and for what has to happen at that point?

The example I use of food production for downstream migrants in the Columbia mainstem is just one of several that we might look at. There are many others. You can look at the spawning carrying capacity, you can look at rearing carrying capacity in the tributaries. But in the context of food, it's fairly easy to both conceptualize scientifically and explain to a layman, Even the layman will understand that you have a house that is suitable for you, that you can get down to the basics of having enough food to eat to keep yourself going. And from a scientific standpoint, we look at that as a bioenergetic model, the amount of food that comes in versus energy expenditure.

So in terms of a portion of the habitat that's important for the fish at a particular stage of its life cycle, and something that we can see has probably changed from the historic condition to the current condition, I see us able to focus pretty specifically on an aspect of carrying capacity and do something with it, come up with some answers and perhaps some solutions for habitat restoration. I see that narrower, detailed approach as perhaps more productive for our thinking about carrying capacity than getting bogged down by all the things that have happened out there that we have little control over and that we would have a heck of a time aggregating to come up with a general carrying capacity for the system.

MS. COGAN: Is there a general definition? Can we say what "carrying capacity" is in ten words or less?

DR. COUTANT: I think it's very simply defined: "carrying capacity" is the ability of that habitat at that time to support a number or an amount, if you think of biomass, of fish.

DR. SIMENSTAD: I'll offer an alternative, which is a need to acknowledge that we are dealing with anadromous species and that, in terms of overall performance, there is no one habitat that necessarily, over time and space, is going to constitute a limiting factor. And that really we are talking about a continuum of very nonlinear relationships from the watershed through the estuary through to the ocean and return. So perhaps increasing the productivity of a particular habitat may be beneficial to a race, stock, or life-history type. But we still have to understand that in any one year, any one circumstance may be immaterial because the living factor may be completely displaced from that system.

So, although I agree with Chuck that it's very important to understand how we've modified and how we might restore some productivity on a habitat-by-habitat basis, I think you also need to understand how we've modified the capability of stocks and races and life-history types to be adapted to variability in that whole continuum. To me that's equally important.

DR. BISSON: As I understood Chucks comments, I think he was asking that the discussion be framed more in the sensitometric form, which is to get down to details and specifics. And in that sense, I agree with Chuck. I think if we try to grapple with some generalized definition of "carrying capacity," the discussion won't be particularly helpful, and I don't think it's going to persuade any of us to change our particulars views. So I would like to turn the question around a bit and ask the people who have organized this, the Power Planning Council and Battelle and Bonneville, what really important questions related to carrying capacity do you face now? What are the key things that you're worried about? What is your uncertainty about a notion of carrying capacity that you would like to see addressed by this group?

Knowing specifically what you would like us to address, I think, would help the panelists. I may just be speaking for myself here. I think maybe the others should comment, too. But I would like to ask the organizers, what are the big problems you face? That will help us in framing our discussion.

MS. BERWICK: What we really wanted to get at to make this as objective as possible is, first of all, to try to get from you people an objective list of the determinants of carrying capacity. And then try to get at how the determinants of carrying capacity manifest themselves in different races of salmonids. I can't just use the word "salmonid" and have it cover the whole Basin, but the idea was to get at the determinants of carrying capacity, how do the determinants manifest themselves in each of the major areas of the Columbia Basin, the tributary, mainstem, estuary, and ocean. Then add to that native salmonids versus the hatchery breed.

MS. COGAN: I think the question is, what is the problem that we are addressing, what is the problem that we are facing, imminent or in the future?

MS. BERWICK: The history of the measure that has been put into the Council's program was the question, essentially how many fish can we put into the river? And has the carrying capacity of the river already been exceeded? Can we continue to put in the number of hatchery fish that we are putting in? Are we putting in more fish now than historically has been put in the river given all the changes over time?

DR. WISSMAR: I think you have to be very careful not to get carried away with the concept of carrying capacity because it is so complex and there is an incredible amount of information out there looking at carrying capacity from the organism's point of view and the system's point of view. Anadromous fish move from a small house upstream to a big house because of space and food limitations and other constraints on the fish, such as predators and so on. As they move out, they get bigger, so you have a size thing to look at. They can get different types of food of different size and density as they get bigger. They can also avoid predators. They swim faster so they can get bigger.

But what Nora hit on is, yes, given historical impacts to this system, we must look at it from a landscape point of view and not get tunneled in on strictly the fish's point of view as far as organismic responses and so on. We have systematically decoupled the system, in terms of removal of upstream habitats, since the arrival of the trappers at a very early time. And we need to step back and say, "Yes, even before we got to this century and started to put dams in, we decoupled a huge capacity, all the way from the estuary to the uplands, as far as supporting fish. We have taken carrying capacity away for 150 years."

So I urge that we use the data we have, but we have to step back and say, we may be able to do a few things upstream that potentially some pretty good fish producers like the Wenatchee are doing it now. But even if we step up fish production, because we have some habitat integrity left and we have some restoration potential there, are we feeding the fish into a death trap downstream as far as predators, temperature, the whole shebang?

So you can step back and take a Yakima River point of view like they did on the patient-template diagnosis? You have to look at the life-history scenarios that are left, and lay that on a landscape scenario as far as how the Yakima is set up now. It's been decoupled by irrigation, grazing, agriculture, forestry, urbanization. How do you really take that template and work with it on this highly modified landscape? Once you get that corrected, what happens when you feed it into some of these death traps, which is the mainstem?

So it's very, very complex. If you get locked in on carrying capacity at the organismic point of view, you are not going to get anyplace. It's one hell of a challenge, and you have to step back and look at it in different scales. You have done that: The estuaries, the mainstem, and the river. But which pieces can we work with? That's the challenge.

DR. MCCULLOUGH: I think in looking at the tributary habitats, especially now in the Snake River Basin where you have the endangered species concern. Actually, you have the same concerns throughout the Columbia Basin; they may not be elevated to ESA status yet, but I think it's laughable to think that the number of fish now in those streams is anywhere near exceeding the capacities of the streams. Some of the data that I've shown does indicate that the survival of fish in some of the very degraded streams is much less than it probably was historically, based on nearby control streams. So, in that sense, I think capacity is reduced. But still there are so few fish there now, I think it's very far from reaching the point where there are any kind of density-dependent limitations. There are still many streams in the Snake River Basin that are in quite good shape and still have very few fish. So that indicates there are some significant mortality factors as you go downstream. I'm sure everyone is very familiar with all the issues of going through reservoirs and passing through dams.

So I think, rather than focusing on carrying capacity from the perspective of tributaries downstream, the critical issue is the high mortality, which makes it very difficult to have the same number of fish coming back to spawn as in the previous generation, which would lead to continual declines. The information presented yesterday about the estuary and the ocean would seem to indicate that there is not a major limitation of food availability in the estuary. But what can we can do about those things?

MS. COGAN: Is carrying capacity a useful way to look at this problem, turning it around?

DR. BISSON: If I could prevail on Nora Berwick to come to the mike one more time, I'd like to follow up on the question, because I think it's going to have a bearing on the kind of answers that you'll hear from the group. You asked a very thoughtful question, and certainly a real one from a practical standpoint. How many fish can we put into the river? My follow-up question, because I think it will have a bearing on our answers for a question like that, is: How many fish can we put into the river in order to achieve what, or conversely, in order not to achieve what? In other words, when you ask the question how many fish can we put into the river, what is the second part of the question?

MS. COGAN: For what reason?

MS. BERWICK: For what reason? Again, the history of why this whole carrying-capacity measure came up and is in the program is that a question had been raised about the hatcheries. Were the hatcheries overloading the carrying capacity for production purposes, or what a habitat could support at various places all the way out to the ocean and including the near shore? The underlying question, then, is, do we want to be producing that many fish if, in fact, that carrying capacity has been exceeded? Then it begs the question, are we talking production in terms of just making a big food supply in terms of agricultural fisheries? Are we looking at genetically sound native stock? Will we be trying to do that and make sure that they are a strong enough stock and deal with the problem in other stocks and deal with the problem in another manner so that you wouldn't need tons of hatchery fish coming in? Does that help at all? I mean, the question is hatchery production versus the wild species.

DR. REISENBICHLER: And how to increase carrying capacity has really not been the focus here? You don't really care -- that's a very minor concern of this gathering?

MS. BERWICK: I don't know that that would be a minor concern. First of all, you've got to be able to define what we're talking about. That's what this whole gathering is about, also. But relative to increasing the carrying capacity, maybe the carrying capacity of the system as it exists now is less than what it used to be because of all the anamorphic changes that have occurred. So that if we were to increase carrying capacity, maybe we have to make some man-made changes. So, it's a combination of the two.

MR. GUSTAVO: I'm Luis Gustavo with the Northwest Power Planning Council. Just to add to what Nora said, we are also trying to identify bottlenecks, which is one of the reasons why we partitioned this exercise into different sections for the entire system. In other words, if it's the tributaries that have the smallest carrying capacity as opposed to the mainstem or the ocean, that would also help us identify how to allocate our efforts. Are we doing way too much in one section of the system that eventually will dissipate in some other section downstream of the ocean or the tributaries? So bottlenecks should be a word that maybe helps your thinking.

DR. MOBRAND: Just to follow up on that. I wonder, bottlenecks to what? To total hatchery production? To the Snake River? To spring chinook? I mean, it's back to the same question that was asked earlier, that is, what is really the underlying purpose? You alluded to it.

MR. GUSTAVO: Just to follow up, also, on your chart there, I don't disagree entirely. I think that we are fooling ourselves if we try to come up with a single number for carrying capacity. And the way we are expressing it right now is as a two-dimensional axis with an asymptote value. To me that doesn't say much. I think it will be better to have an envelope kind of distribution with multi-axes or a multidimensional envelope with time, perhaps, being one of them, which adds complexity to this effort. But in that envelope you include all the fish you want to see out here. I don't think it's useful to refer to Snake River fall chinook alone. Because the system does not particularly draw that much of a difference between species or races. The system is like the big mother.

DR. MOBRAND: I'm just suggesting that the bottleneck will be very different depending on where you are in the river. For example, a bottleneck to an upper-river fish may be the mainstem or the lower part of the tributaries, lower part of the Snake; whereas certainly a downstream hatchery fish would experience a bottleneck in a different way. There can't be a single definition of a bottleneck in all of the Columbia. I guess there is some underlying priority or diagnostic species that you are using both to define "capacity" and to define "bottleneck."

MR. GUSTAVO: Right. First, that's why this exercise is not easy. Second, that's why I propose the envelope thing, which is, again, not easy, and, third, maybe we've got to look at what's hot and burning right now and start with those. But maybe you think differently.

DR. MOBRAND: I think the concept makes sense, but it needs focus. I think it's fine to talk about details and talk about focus, but the region needs a priority. It needs to find a rational way to make decisions about hatcheries and hatchery production. And I think the answer, at least in part, is to find the focus. And the focus would have to be on maybe looking at individual populations, and follow -- like others were saying -- the whole life history through to determine where the bottlenecks are, where density of other populations are critical to the survival of an individual population. And if you look at a sufficient number of those, and select those wisely, I think the exercise is doable. I think you can take a broader view and get a perspective of the effect of density through time and space, the effect of hatchery fish on natural production through space. But I think you have to do it through a focus on some population, some well-chosen indicators, if you will, that give you some of the patterns, tell you where some of the problems might be in time and space. I believe that there will be no clear-cut answers. There won't be one place where you make a change and it's going to solve all the problems. You have to make some tradeoffs.

MR. GUSTAVO: I agree that you have to pick some of them, and perhaps you can't do them all. Mainly, you know, with the change of (unintelligible) and deterministic process is acting alternatively, that's out of the question. You will never finish. And I want to see it done.

MS. COGAN: That really leads to the second part of our questioning. What are the determinants of carrying capacity? What are the most important ones from your standpoint, knowing that the decisions will have to be made, and they won't be all in one basket, and a lot of these decisions are political. But from your standpoint, what are the most important ones?

DR. HARTMAN: I would just say that it's going to be continual, depending on which stock you are looking at. Obviously if you are a stock that spawns in the very headwater of some tributaries, the most dominant factor in your life history is going to be passage through the dams and passage through the fishery. I was doing some back-envelope calculation, which I won't share with you, but it seems apparent that there is sort of a grading there in terms of the importance of these dams relative to life history. I think that's something that maybe we can't do a lot about in terms of modifying a source of mortality. But you have additional moralities, we know that most populations' natural mortality may run between 20 and 40% of the population a year. So if we have other things such as reduced growth in any one environment that causes us to have either slower growth or delayed age of maturity, those are additive factors and they are going to have a differential impact on different stocks depending on how important these other sources of mortality, such as dam passage, are.

So, again, I don't think there is any one thing that we can point to. But I think maybe one approach would be to do some really simple modeling calculations where you look at the estimated moralities for a given stock to get to their spawning ground and back. And I would suggest that maybe one determinant that you might look at, or one way of evaluating that, would be the number of adults that get back and spawn. And we know that there are certain factors we can control, and certain ones that we can't. What ones can we control? And some data presented yesterday suggests that oceanic conditions are not as favorable as they once were, and that's probably something that we can't control at all. But there are certain things we can.

MS. COGAN: But you've got passage through the dams as one determinant. Others? Why don't we see what kind of a list we can make and then go back and set priorities to determine which ones we can do something about?

DR. BOTTOM: This probably jumps us back to where you don't want to be, but I'm still struggling with the first part of it. And I guess one of the things that I think is important is that we try to keep separate the notion of the potential capacity of the system based on some wide array of factors; that would be some overall potential under a given array of conditions versus what's realized by the system. And if we are going to put it in the specific context of salmon, then I think we can probably all say that in the case of hatchery fish we can probably do things to realize more of the system's potential than we are doing today under the given array of conditions we have. We also could say that we might be able to increase the overall potential of the system or to realize more of the potential that is there. We might also be able to realize the potential of the system from what it is now. And that's where we get into some of the historic conditions.

We also see that idea when we look at some of these shifts and climatic regimes that we talked about as an example. There may be many different shifts that we don't know about yet; many different states of the overall system that naturally are changing that overall potential. It looks like we are not going to produce as many salmon in a particular year under that type B circulation we talked about yesterday as under a type A kind of situation, just in terms of numbers. At least the overall system seems to change both quantitatively and qualitatively between those states; the relationships shift and the overall potential of the system shifts. Maybe this comes back to the envelope idea, but this whole system may be shifting between a different pattern of envelopes over decadal or longer kinds of cycles. And so what I think this implies is that we shouldn't try to come up with a number or a prescription or trying to develop a basis for hedging our bets the best we can into the future. And some of the things that Lars said, I think, are there. Some of the things that Pete Bisson talked about yesterday, that putting some resilience back into the system will have the greatest likelihood of both maintaining the persistence of the species itself and their capacity to dampen these natural fluctuations through time, to even it out and not swing wildly between these states, which is a function of what diversity does. It provides that filter of a system.

So I would argue that we need to keep separate this overall potential versus what's realized, keep those clearly in mind, and then we also need to perhaps think of it overall in terms of not just a quantity, or even just a quality, but also the resilience of the system.

DR. REISENBICHLER: I should take the time to come up with an hour lecture, it feels like. But I guess the point I would like to stress now is that I agree that carrying capacity is a useful concept, even though we have done a pretty good job of avoiding defining it here. But I think it's really crucial -- it really frightens me to think that it can be taken as an absolute number. And that it's easy to forget that it represents a continuous relation, like Lars has shown up here, and that, indeed, particularly with hatchery smolt releases, the potential -- or any other kind of hatchery, at least, I guess -- the potential is to push the population up to carrying capacity, or past it, which is, of course, what you are worrying about.

But even to push it up to carrying capacity, depending on the shape of that curve/linear relation, we reduce the marginal -- we get marginal decrements in the survival of all populations. We can -- if we had some hypothetical system and we've got it at half, it's running at half carrying capacity, we build a mega hatchery, boost it up to full carrying capacity, we may well be actually losing some of the small components of this meta-population that have relatively low productivity. The increased mortality in those populations can simply push those below the replacement line and out the door. So I just throw that in as a warning. And I guess if we do move closer to a definition of carrying capacity, I would like it not to be divorced from these continuous relations. We should -- numbers are good, but we really should hesitate in many situations, and I'm thinking, well, of many situations to actually achieve carrying capacity. We should -- when I think about ideal supplementation programs, then, of course, an ideal one would be none of the genetic impact that I discussed yesterday. I don't think about pushing these populations up to carrying capacity, but somewhere --obviously somewhere with increased abundance, but not up to where we are really pounding the weaker segments of the population.

MS. COGAN: But, obviously, we have to know when we are there or when we're approaching that. And someone has suggested the passage through the dams, the mortality rate, the potential of the hatchery fish, and we know what that entails. And then the climate changes, the natural changes that we can do very little about. And we heard some very, I think, eloquent remarks about El Nino yesterday. What else are we talking about here?

DR. WISSMAR: Safe passage through the dams. What happens after the dams? Well, probably some people know more about the estimates than I do, but in a lot of these systems they estimate escapement by -- the difference between what passes through the dam and what's taken at the hatcheries. So there is a huge error if you say there are so many fish going into some of these basins like the Wenatchee or the Methow. But there are some confirmation corresponding surveys as you go out and get an idea of the number of redds in the distribution, the nest that the eggs are going into.

But still, there are some huge errors in there. If you step back and say, okay, I'm taking this landscape point of view. I know that the Methow is in pretty good shape given the whole watershed, erosion, riparian zones, human density, so on. The Wenatchee is kind of that way, too. They are both pretty good as far as having resiliency, like Dan was getting at, if you look at the system's point of view. They both have pretty good flow regimes throughout the year. They both have cool water through most of the year. Well, this tells us that here are some models, like you'd look at some models inside a smaller watershed, as far as key habitat, side channels, cool refugia, as far as temperatures, springs and so on. Here are some big models on the landscape that have resilience.

Let's go back to FEMAT's plan, as far as the federal government's riparian research or key watersheds and so on. Well, let's make sure we reserve these basins, They may be 500 square miles or 3000 square miles, but they are reserves for the future. We've got to make sure that we secure those, make sure that we understand what is happening for our spawning, seeding. Indeed, are there enough habitats for the juveniles out there, the right type of habitats3 You may have a lot of habitats, may be the wrong habitats, may be all ripples. Do we have something, a hedge, for the future?

As we start tuning and we are placing these models upstream, downstream, the Wenatchee does better. It's farther downstream. It doesn't have a density-dependent -- independent -- as many variables working on it as the fish go out downstream as, say, the Methow does. The Methow has to go a little bit farther, more predators, more temperature problems. Let's secure these areas and then work with what we can do with the mainstem as far as manipulation.

And I think those are our options. We don't have too many. So I'd say, I'm looking at carrying capacity from a landscape point of view. And there are some things with the data we have now that tell us what direction to go.

MS. COGAN: All right. So there are models or parts of models?

DR. WISSMAR: There's data and there's enough -- there's information out there where we can develop models at different scales. Not just habitats inside a watershed, but you can have watersheds and tributaries inside sub-basins and sub-basins inside the Columbia. So you do have these things to hedge our bets.

MS. COGAN: So landscape is important, scale is important.

DR. WISSMAR: You have a hierarchy of all these systems, space, and time, how they operate through time, because they all have different service regimes, such as different flow regimes.

MS. COGAN: What time is appropriate, would you say, everybody now, eons, years? We have heard decades.

DR. BISSON: I sensed from Nora's comments early on that what the Council would like to have is something that was at least reasonably quantitative and predictive enough to take us in the direction that you could do adaptive management type -- you could make adaptive management-type decisions and learn from your experiences and correct it. Because we are talking about models, and what I want to say has to do with models.

MS. BERWICK: What we wouldn't expect, even though it is something that's in the program, is what is the carrying capacity for salmonids in the estuary. I mean, that's unreasonable. The sort of thing that we would like to get at -- and I sort of feel that everybody is sort of getting it, but the pieces aren't put together quite yet.

Getting back to the list of the determinants of carrying capacity, that helps one define carrying capacity. And mainstem dams are not really a determinant of carrying capacity. That's the source of impact that has reduced something that was important to the salmonids passing through that segment of the Columbia, but it reduced something. So what did it reduce? What are those determinants? That is the sort of thing we are trying to get at, so we know what management actions to take and what further research we need to do.

MR. ASKERN: Dave Askern from BPA. Let me just throw another question in this. You have two time scales which are of interest, one of which is the programming portion of the Council's, which looks at long-term objective goals. My perspective and experience with BPA is with that in-year action; what you do this year with the waters that you have available for the benefit of the stock, recognizing that you have finite resources. So the capacity definition for the long-term effort will be different from my in-year definition. So we have these two possibilities for definitions. And those definitions will depend not only on this time scale, but on your objective.

In the program, presumably, your objective will be something of a resiliency issue, a quality issue, diversity issues; whereas with the in-season issue, you are talking, when do we release? What waters have we? Do we target adults, juveniles? If it's juveniles, which groups? Issues like that, very specific quantitative action-required decisions. We have two scales, which we would hopefully address in the definitions and in the determinants.

DR. BISSON: Those are very good observations and a good indication of the two related dichotomy of scales; that you are working on the short term and the long term. Here, I think -- and I will deliberately try to be a devil's advocate. We could put together a laundry list of things that we think affect carrying capacity. And we could come up with assumptions about those things for different species and put together some, at least semi-predictive relation-ships for how our ecosystems might respond to changes in these things and how our management -- i.e., how many fish can we put in the river -- might be based on some of those. And case in point are the way that the models have been used to determine the strategy for the downstream movement of salmon from the Snake to the ocean. The main comment that I want to make, though, is that I think the way we have gone about that scientifically probably hasn't been the right way to do it. I guess I've gotten to the point now where my skepticism of deterministic models is so great that I've become more of an advocate for the kind of experiments that Carl Walters and Ray Hilborn are arguing for, the big scary experiments where we really push the system both ways.

And an example might be on the hatchery side, and I forget exactly what the proposal was, but I know it was quite frightening -- was to eliminate it or cut it in half for a couple of years on a very large scale, and then double it for a couple years. Really push the system big-time to see how the system responds and try to learn from those big experiments. Because I think that it's like passage of fish over the dams: We can tweak the dams, but I'm not sure that we are learning enough. Because of the inherent variability in all of these things, that we're not getting the answers that we want. I think we ought to try a slightly different science. And I'm sure that other people up at the table here probably feel a lot of discomfort with that. But I'd like to toss that out as a discussion point.

MS. COGAN: All right. Taking the bold approach.

DR. COUTANT: I think that's a good idea. And I guess the thing I'd say is that we're doing it.

DR. BISSON: Yes.

DR. COUTANT: We've got some major experiments going on out there right now. And I'll go back to my example. We've essentially wiped out the mainstem productivity of food, and we're seeing the effects. We just need to look and measure them and make some changes. We've got a big-time experiment going on now about what happens if you wipe out 80 or 90% of the fish going downriver every time? Not disagreeing with you in that we ought to manufacture a few more, perhaps, to get a critical look at some of the questions. But we've got some big-time experiments going on out there right now.

MS. COGAN: Are they overt, though? I mean, they are happening, as you pointed out yesterday. But are they actually in the experimental mode so that we are looking at them and we are judging them and making decisions, analysis, and so on? It's happening?

DR. COUTANT: Not to trivialize it, but it is kind of like when a tree falls in the forest and nobody is around, is it making noise7 In a sense, the experiment is going on, and we've got some experimental areas, some control areas; the things are happening. We are just not out there to listen to it in the sense that we are not out there taking the measurements to find out, to learn from it. We have a lot going on. And if we just focus our attention on some of these, I think we can learn a lot without actually making more experiments.

DR. PEARCY: I think one of the problems is we have maybe too much going on, in many cases. We don't have controlled experiments. And what we do in freshwater, for example, may be completely masked by what happens in the estuary and the ocean. So we need some way to segregate, it seems to me, the effects of upriver habitat, below

Bonneville, estuary, and ocean so we can actually find out what is happening. What I like to think of -- maybe this will be useful or not -- you ask three questions: You ask when, where, and how. And the "when" question is when in the life history and what time of the year is critical and what's happening. Where are the fish at various times? And the "where" question is, where are these and where is the action occurring? Is it freshwater, the estuary, or the ocean? And a lot of these things, I think can be addressed, and we talked about this before, by doing experiments.

. And I think we have a marvelous opportunity in the Columbia River with all the hatcheries, and the possibility of doing experiments; long-term experiments, probably more than just a couple years. Because I think you have to make sure that the conditions in several environments are constant while you are modifying things in the other environments. So it's not something you can do for two years. It should be long term. And you have to have a lot of good control. And I think that's the secret. But I think the technology is getting so maybe we can segregate where things are happening.

But the big question, it seems to me, is the "how" question. What is the mechanism? What are the processes that are really important? Unless we understand those -- like we thought we understood out in the ocean with upwelling, and then things flip-flopped around, which really means that we don't understand how upwelling, for example, affects the survival of OPI coho. So we have to get at the mechanisms. We have to know what's happening in order to really interpret these experiments. And I think that, again, is going to rely on monitoring, long-term monitoring, process-oriented research where you're actually doing experiments with different hatcheries or different systems and long term, under control. And also modeling. I think all three of those things have to go on simultaneously.

MS. COGAN Back to the template of the questions to see if we can get any further. Are there other determinants? We've mentioned the dams, the hatchery fishes, the natural changes. Resiliency comes up, I think, time and time again. And, of course, along with the natural changes in water, the importance of cool water. I mean, are you willing to vent any others, any other determinants that will or do affect this survival?

DR. MOBRAND: I think when we're talking about carrying capacity, we're probably simplifying the ecological impact of the abundance of fish throughout the Columbia River. And most of the discussion seems to focus on competition for resources. There are many other things that go on in that environment that also affect survival, such as predation, which may operate very differently from competition, for example. So I think other ecological factors -- looking at the ecological impact of abundance in a broader sense --I think is more important than understanding the effect of abundance on survival.

I also think that all of these density-independent factors that affect survival also have a direct relationship on carrying capacity. You know, it does mathematically and in the models, that is, the deterministic models that we use, and I think it does in reality. Capacity is, in fact, affected by all of the factors that we've talked about, including the freshwater survival, by life stage, ocean survival, etc.

DR. WISSMAR: I think I will go along with Pete. I think we need some new experiments. Dan Bottom hit on it yesterday, just that we have linked carrying capacities, just by the nature of salmon and their life cycle, as far as the headwaters to the ocean. Well, what's the big decoupler there? It's dams. We all know that. All right. We have maybe a chance to do some experiments near the oceanic system. There has been talk of removing the Elwha Dam on the Olympic Peninsula. What is the recovery potential for the habitats, for the landscape, the river drainage, and also the different fish that are going to use that? We don't know what happens in space and time on those scales. All right. You do that experiment. There has been talk -- Reg can tell you -- about the NBS baseline inventory work (in cooperation with Olympic National Park personnel) in the Elwha River system in anticipation of reestablishing anadromous salmonids in the mid- and upper portions of the watershed. Also, we need to know the same type of information upstream. And there are few places that we may be able to do this, like on the Wenatchee and Tumwater Canyon. There is a water-diversion dam. Come in and say, where can we pull some of these bugs to get an idea of the capacity physically and biologically. How resilient, truly, is it?

So there are little experiments out there that we can do by these manipulations. I think you are going to get a lot of information fairly fast on certain aspects of the system.

MS. COGAN: How do you help our friends at BPA who need some answers this year or next budget year?

DR. WISSMAR: I think they ought to look at the history of what we do know as far as the operation of the physics of the system and the biology. It doesn't happen in a year. All these different watersheds are on different scenarios given their physical disturbance regimes and how the fish template on top of that reacts as far as their evolution and adaptation. So if you want a Band-Aid, I think that's a death wish, if you think you can do it in a year or so. That's been our problem all along as far as the way we do a lot of things: We want a quick fix.

MR. ASKERN: Just context, if you have a given water year, and looking at it from the perspective of strictly operation of the water hydro-system, you have a choice in a water year of where you use the water temperature control to benefit, perhaps, the passage of the adults or volume control to benefit the downstream passage of juveniles. Traditionally we've tried to balance this. And whether you have been successful or not is in the eye of the beholder. If you have a particular year in which, from the best of our understanding, there's no chance in hell of the juveniles surviving because ocean conditions are bad, for example, well, you would like to target the use of the water to the adults. That's one choice, one scenario. Our definition of capacities change, or at least it's got a definition that allows for decisions between different water years, for example.

The point I want to make is our carrying capacity definition has to be responsive to operations in a particular year. It's not just our hydrosystem operations, but it would affect your habitat decisions in the same way. Are you going to target your adults and target your spawning conditions upriver or other things downstream?

DR. WISSMAR: Wait a minute. Given the constraints of your operations, where do you have the most room to do some of these experiments? Which parts of the sub-basins in the Columbia could you do some manipulations? Where do you have the room to do something to get some new ideas as far as management?

MR. ASKERN: Wherever the law allows. I'm afraid that's my answer. It depends upon where we're --

DR. WISSMAR: So you don't know? You'd have to look at it legally before you looked at it from --

MR. ASKERN: No. I was more referring to our primary duty as a funding agent for much of the work that goes on. And wherever the region decides the work should be done is where it will be done.

MS. COGAN: Can we get move on to the biotic and the abiotic, and is that a way of dividing these determinants?

MR. YON: My name is Don Yon. I'm with the State of Oregon Department of Environmental Quality. And I'm on the lower Columbia River Bi-State Water Quality program. We have been dealing with some of these issues. I mean, as part of the Clean Water Act, we have to protect beneficial uses. We have done about four or five years of study of the water quality. And we've done both water ambient sediment and fish tissue, and we are also looking at the impacts on the productivity of eagle eggs and mink and river otter. And trying to also identify what impacts some of the contaminants we are finding in the river are having on survivability of fish. However, we haven't had the funds to really be able to adequately address that issue.

I guess one of the determinants that I'm not hearing much being talked about is what impacts pollutants might have on the survivability of salmon. We know that in some of the studies that NMFS have done in the Puget Sound area, that in comparing the passage of smolts through Duwamish comparing that to the quality, that they did show some lack of survivability. And that's a question that we do have in the lower Columbia River. It's important to us to be able to identify those impacts, because as we move into the National Estuary Program, just -- both governors had recently requested that the EPA designate the lower Columbia River into the National Estuary Program, which we just recently got that. We are gearing up to be able to develop our management plans. And part of that management plan, at least for the lower Columbia River, will be able to identify what impacts water quality are having on protection of all beneficial uses. And we will be developing specific management measures or proposals, and we want to be able to do that with all the different state and federal agencies and other state holders within the basin. So we have a real need and use for this data. Obviously, it isn't important to the Power Planning Council and to others, but we think one of the key components is looking at the impacts on survivability of salmon. Our studies are showing that the contaminants that we are finding, which are primarily PCBs, dioxin/Furans, DDE which is a derivative of DDT, arsenic, and one semi-volatile are having the'greatest impact on long-term consumption of fish within the Columbia River in terms of human health. Some of the work that Dr. Chuck Henny is doing with the

National Biological Survey in Corvallis is also showing some impact on the reproduction of both river otter and mink in the lower Columbia River; so much so that it's actually -- you know, as someone has addressed, it is affecting their hormonal system. And we are waiting for the results of that. But that question is still being raised, and what impact that might have on salmon.

All the other issues you have identified are critically important, but one component of the environmental part of it is, what impact could these contaminants have? We don't know that. That's a major research thing. I think, though, that the National Marine Fisheries Service is probably gearing up to do the similar studies it did in the Puget Sound for the lower Columbia River, and we support that and hope that does get done.

DR. WISSMAR: Do you have any experiments you can propose relative to the estuary or how we can get at some of these questions?

MR. YON: Yes. I think we have a Fish & Wildlife technical advisory committee. And a lot of the issues that came up, we're looking at the food-web relationship. Some of the stuff that Bob Emmett has been particularly interested in is looking at the uptake of contaminants through the food web, because we are seeing the bioaccumulation in the fish tissue; particularly surprising was in salmon, chinook, coho, and steelhead. Our data also shows that the contaminant levels were higher in males than in females.

So you get into that whole issue of why are we seeing it higher? You get into that question of, where are they picking up the contaminants at different life stages of the salmon? And looking at the importance of the plume from the Columbia River on the salmon in the ocean. I don't think there is much data that we are aware of contaminant levels of salmon the ocean. So, to go through the whole life history -- but most importantly the biggest bit of information that is missing is, is there an impact of these contaminants on the reproduction or survivability of salmon? That's the most --

DR. WISSMAR: Coming through the food web?

MR. YON: Yes. That's right.

DR. WISSMAR: Say, let's do another experiment. Si showed the systematic removal by levies, and so on. And the shrinking of habitats in the lower 30,40 miles of the Columbia River as far as the Willamette down. All right. We have taken the carrying capacity as far as habitat space away from the fish. All right. We have decoupled the food web or changed the food webs. So you want to know something about the bioaccumulation of the food in the fish as it comes through the food web. Why not do an experiment where you kick the estuary into another mode, such as recovery? Let's reach some levies, get some habitats back, watch what the fish do as the food webs develop in these different systems.

We know when you have greater diversity in estuary and habitats and other ecosystems, that you may have more of a cleansing opportunity, too, because the food web becomes more diverse. This may be another experiment. Once again, you're putting some habitat in reserve as we tweak the mainstem.

MS. COGAN: All right. So you're suggesting doing it from the habitat standpoint rather than from the elimination or control of pollutants, which --

DR. WISSMAR: We can do that, too.

MS. COGAN: That's a traditional --

MR. YON: Yes. And we get into that whole debate. We've tried to address that issue in the bi-state program, is the impact on beneficial uses being caused by a pollutant? You know, because when you are dealing with a regulatory process, that is going to be the first question. Or is it really habitat? Building upon the work that CREST (Columbia River Estuary Study Task Force) or CREDDP (Columbia River Estuary Data Development Program) has done in the lower Columbia River, we've completed that mapping, that 18 16 18 17 mapping up to as far as the maps that were available, which is up to Portland. We have those right now. We also have contracted with the Army Corps of Engineers, who has contracted with OSU, to do photo-interpretation, using the latest, which is 1940s on, of the habitats so we can compare through time the habitats that have been lost.

And then they are going to come out with a recommendation saying, here are the specific habitats that need to be protected right now. Here are habitats that have a potential for being rehabilitated, and that could be part of one of the early actions that the Estuarine Program could do. You know, in looking at pollutants, it's not only the toxins. It's the temperature, it's pH, it's dissolved oxygen. And we have data that we have collected over time. And I would strongly support the suggestion, because that's a strong suggestion we are going to come out with, that we have to have some long-term monitoring. And it has to be coordinated, state and federal, looking at not just water-quality parameters, but it's looking at biological and other habitat changes over time to really be able to test the effectiveness of any activities that we do or other agencies might do to clean up and increase the health of the system.

MS. COGAN: That's very helpful. Are we able and willing to make a priority list of these determinants? Is any one or set of determinants more important than the others? Anyone want to get started?

DR. BOTTOM: I think one thing that is helpful, I think most of this at this table could come up with some hierarchy of controls on biological systems that seems to be important. And I know when we look at -- at least a way to array our thinking. And when we look at things like fish communities in estuaries, both qualitatively and quantitatively, you immediately see a continuum of differences when you make comparisons based on morphology of the estuary and its latitude, because we don't have any control of the latitude of the estuary.

MS. COGAN: Not today, anyway.

DR. BOTTOM: But we do, but in a most fundamental way. We have altered the size and shape of that system so that the absolute quantity of habitat has changed, it's there, as well as the quality. And we have done that in two ways. One is in the spatial sense, that we've confined the system in a variety of ways. Say in the estuary, whether we are talking about marshes or whether we are even talking about jetties at the mouth, we've basically altered the shape and dynamics of that system in some ways that probably had not been beneficial, for the most part. We've also done it, I think, in a temporal sense. If you look at what the life histories of wild stocks tell us is that they partition that system throughout the year. They find a way to use it all the time.

Our hatchery program tends to concentrate things, and so we have changed the system in a temporal sense, also. We have made it smaller or qualitatively different, simplified it. And we have also simplified it in the sense of the way we have concentrated things through time. So those, to me, are -- if I put in the very hierarchy of things of where we have the most impact, it would be just on that net amount of what's there and how it's partitioned. And we can see that. That is something we have a very little direct control over. And that is something that carries through all stages of the life cycle, at least up from the freshwater to the estuary.

MS. COGAN: Anyone want to build on that? The net amount -- and we've all agreed and we've had many examples of how we have altered that over time, someone said from the first European man to reach these shores. What else? What other determinants that you can put on that priority list?

DR. MCCULLOUGH: I wanted to add one thing to what Dan said about partitioning of the available resources. I think there is probably additional capacity in each of the tributaries that we were talking about for producing fish. In cases where certain species have been eliminated or reduced to very low numbers, each of those species would have, you know, a capacity to exploit the available habitat there. And having more species using the same habitats, of course, they are going to partition the available space and the food. There is some overlap in the use of the resources. So it's not clear exactly what the total production of smolts would be when you have multiple species, native species versus just, say, one remnant species. But I think that there could be more opportunity there, too.

DR. SIMENSTAD: I would like to reinforce that, maybe from a little different angle, more than just necessarily fish packing into a diversity of habitats. But the major criteria would be diversity in the population structure that reflects a very prolonged demography of resonance in these different habitats. More from the standpoint of increasing the resilience to various bottlenecks that occur both in the habitat and *(unintelligible)*. In other words, I think one thing that Lichatowich and Mobrand illustrated quite dramatically with a little data is that we have highly truncated the demography of the fish populations in the system. And that there has been one very potential source of decreased resilience in populations. That's a major factor. So from the standpoint of increasing opportunity at any one time and space, the thing is to increase the resilience to withstand variable events over time.

MS. COGAN So there is a respect for nature we are hearing here, or for going back to understand those natural systems and help them along.

DR. BOTTOM: Yes. And I think what this is pointing to, and it comes back to your original question, is that the carrying capacity of that system for wild salmon and its carrying capacity for hatchery fish may be two very different things. I mean, we know at least the realized capacity for hatchery fish; it's what we get back every year. Whether that represents some very tiny fraction of what is possible is perhaps what you're more interested in. And the way we get at that, I think, is by comparison and analog to what was produced naturally and how that occurred. What strategies have evolved through time to allow that system to maximize both its resilience, persistence through time, and its productivity? And that question, I think, is basically an evolutionary one, It is size talking about life-history strategies. And I mentioned the basic change in system habitat. It comes back to the patient-template idea, that those are the same thing. To the extent that we remove the habitat, we are not just changing the quantity of fish, we are changing qualitatively that system's ability and adaptability through time, so that life-history type may not be able to express itself anymore. So we have also changed its ability through the run to spread its use through time and space. So this is what I think we are talking about in changing this idea of carrying capacity from its traditional sense, which was a number, an amount, to one that comes more closely to understanding why these systems have become organized as they are. Placing it in evolutionary terms as to how that has occurred at all levels, including stock and life histories of salmon.

We could also ask that question in terms of the fish community and its organization. Why has it organized as it has? We can look at it through an historical framework which shows how it's changed, what life-history strategies have been winners and which ones have been losers. Which, in terms of our changes imposed on the system, gives us a notion of how we might be able to put some of that back, perhaps which ones that have been most vulnerable, and what habitats have caused that loss. So there might be a greater ability to make use of comparative kinds of studies to get at some of that. We have only one Columbia River, but we have a whole range of different effects on it, we can look at what life histories have dropped out. We also have the Fraser River system very near that we could make comparisons with. The Fraser has had less dam development and is very similar in terms of amount of freshwater coming down the system. It is the closest system to the Columbia, both latitudinal and size-wise, and might give us an idea of potential, of how that system is organized compared to the way the Columbia looks today, and how we might be able to move the Columbia system back to something we consider more desirable.

MR. ASKERN: Is there any benefit to turning this perspective on its head? Kyle Hartman yesterday gave us a perception of carrying capacity from the fishs perspective, where you overlay a number of parameters and come up with the desirable place for a fish to be, depending on its size. Can we look at carrying capacity from the perspective of the fish, a year class, for example, recognizing that they generally pass through each life stage or each ecosystem serially, but they have to return up the river, and you will have competing interests --juvenile, adults -- again, But looking at the environment from the fish's perspective, the adult is going to see a carrying capacity that is different from the juvenile's. We are looking at our definition now in terms of long-term scales or each stage of the physical environment. But is there a way we can turn it around so we can integrate the capacity that the fish experiences in its entire life? What benefit is there in that? I'm not sure. But it's a different way of looking at carrying capacity.

DR. COUTANT: Yes, that's an approach that I think we really need to take. I don't think we can emphasize that too much. It takes the question that we've been asked about listing the physical and biotic determinants and says that just about anything you can put on that list will be important at some time in the life cycle. You go incrementally down day by day. You can make it a day-by-day step model or almost a minute-by-minute step model of the life cycle and say at that point, what's the crucial, perhaps limiting, factor? Just to pull a few out of the air, there's lots of dissolved oxygen in the Columbia River. But dissolved oxygen in the gravel where the egg sits at a particular time may be the critical limiting factor. A day later, when that fry is popping out of the egg and has to make it from his little crevice into the gravel up into the mainstem or mainstream of the river, the critical factor may be the amount of fine sediment that's built up in a little layer on the top of that sediment. So its a different critical factor. You go the next day, the next moment, and that little emergent fry that is sitting in the gravel now has to get to someplace so he isn't just tumbled away and beaten into oblivion. So the critical factor may be the current and turbulence patterns that let him get to shore from wherever he came out. The next step is, is he going to find a bit of food to eat when he has to start feeding?

So I guess what that tells me is that the exercise of listing all these determinants could go on ad infinitum. But I absolutely agree with your trying to look at the system from the perspective of the fish to try to figure out, at each step of the way, the possible limiting factor, and then focus in on what that factor could be at that point.

DR. McCULLOUGH: I think another way to look at what you're describing there, which I think is just a large system view of carrying capacity or ability of the entire system to produce fish, would be to arrange a series of watersheds hierarchically. If you look at, say, a sub-basin in the Columbia and then go into particular tributaries of that sub-basin, there may be certain high-gradient streams that are part of that watershed that may not allow fish passage up into those portions of that watershed. And other parts of the basin may have low-gradient streams that are more suitable for the production of chinook. So when you look at the production of that watershed as a whole, it's limited by the components within that watershed. There may be an inability for many fish to move into certain areas that have really nice-looking habitat, that looks great to a biologist who goes out and surveys it. But, in fact, the steep gradient getting into that area still limits the ability of eggs to be deposited in that area and for the habitat to be really utilized.

And so the watershed as a whole, then, the integrated capacity to produce fish is a result of the cumulative interactions of components. But then when you step back to the Columbia as a whole and look at the effect of the dams, I think in a way you can say that those are similar to steep gradients. The dams limit the number of fish that can get upstream. So as a result, the capacity of the entire Columbia becomes reduced because the potential of any of the sub-basins to receive eggs is lessened. So it's not to point out that the dams are the only problem, there are problems throughout the entire system. But it shows that watersheds, even to the scale of the Columbia, can be reduced in capacity by some of those factors.

MS. COGAN: All right. Do you have any summing-up comments? What I **hear** is we know what carrying capacity is not. It's not a number. I don't think anyone here would even hazard to say that it should be a number.

DR. BISSON: This isn't a summary, but just a quick observation. The question they have asked is a good one, and I certainly agree with Chuck's response to it. I'm a little uncomfortable, though, with what that kind of knowledge might lead to in terms of management decisions. Because if we did have a picture, such as the nice graphical displays we saw yesterday that Kyle showed, we might find, for example, that the optimum habitats of bluefish and striped bass might not be the same. Where does that lead us in terms of management decisions? Because if you manage the flow in the river for the downstream transport of spring chinook, maybe that's not optimum for steelhead. That still leaves you with a gap as to what ultimately are the criteria you are going to use to make those decisions. If we are, in fact, going to manage habitat, how do we do it? That, to me, is a central problem. Because optimizing or managing for one species is in many cases not going to get us where we want to go with other species. And I think that's a problem in the Columbia and elsewhere.

DR. PEARCY: On our list of biotic determinants, there are many

things that haven't been mentioned, like BKD and nitrogen supersaturation. But, in general, we are focusing on salmonids. And salmonids are only one very small portion of the ecosystem both in the river and certainly in the oceans. And they are not in isolation; they interact. I don't see how we can ever talk about the ocean without talking about other species. We mention predation, which I think is probably a key factor in the ocean. But we haven't mentioned things that buffer predation, which I think is really critical. I think other components in the system -- for example, the abundance and distribution of predators that usually take anchovy and herring and small fishes, rock fish, etc., -- are critical to the survival and predation rates of salmon. For example, when there is a good year class of herring, the size of coho salmon, and then the predation rate of coho salmon by hake and other species is much lower than if you have very few herring and a given number of coho salmon.

So what happens in the ecosystem has to be looked at. We can't just look at salmonids. We have to look at what's going on, not only with other species, but I think also the area and the distribution of those areas in time and space. For example, if upwelling is intense, you have a big, broad area that the fish is going to inhabit. If upwelling is very weak and you have a very narrow zone, things are compressed near shore, and then you have much more severe effects from competition among salmonids and other species, as well as more severe predation rates.

MS. COGAN: Anyone else want to deal with the last part of that question which is the biotic and abiotic?

DR. WISSMAR: I think it's important to ask the question from the fish's point of view. I showed some examples yesterday for the Chewack, and there were indications that that system is under seeded. But the first summer after they've hatched, a proportion of the par, maybe 30 or 40 of them, leave. They redistribute in that system. Why do they redistribute even if that system is under seeded? Are optimum habitats not there? Lack of food, temperature problems, no water7 You have a decline in the hydrograph and almost base flow conditions. We are getting to those things, but we just have pieces for some of the basins. So those things are in the mill, people are thinking about it, people have done it for the Wenatchee. But there are still many questions there about redistribution of the fish. What does that really mean in the overall equation? So we do have pieces and ways of thinking about this, but we haven't really coupled them together for one fish to the system's point of view.

DR. HARTMAN: What I think might be useful -- and I don't necessarily want to be the one to lead this, not being as knowledgeable as the other panelists about this -- would be to chronologically go from, as Chuck started out with, the time of emergence, what some of these critical factors might be in terms of the life history and success and survival of these fish. Because I think what will emerge is that -- although for an individual at a given point in time this may be the critical factor, and that will vary depending on your age, etc. -- there are certain things that are causal factors that contribute to critical factors, such as availability of food. I keep going back to Chuck's talk yesterday in terms of having more food, because now you've got some vegetation that is being colonized. That also can contribute in some of the riparian areas to controlling turbidity and things that might also affect other life stages. We might find in the long run that there are certain factors that we can manage. And, although we may not be able to come up with a consensus, we might be able to find several factors that can be mediated by one management action --

MS. COGAN: Or at least some guidance to BPA and the Power Council. Any other questions before we have our break?

DR. REISENBICHLER: Just for the record, I would like to repeat the suggestion that the panelists could spend a long time on this list, although it doesn't seem very productive to do that right now. Many of the other items that you might be fishing for on this list were presented yesterday. In other words, I'm not going to harp on you about genetic quality, for example.

MS. COGAN: No. You are just going to mention it and see what to do with it, right?

DR. COUTANT: Just one thought to leave us with. And it may be a little segue into the management part, too. But these fish out there have evolved into a system that is anything but constant. And I think it's important to think about -- as others have mentioned, it's not a new thought, but something to be reminded of -- how the system out there has fluctuated wildly. There were high-flow years, low-flow years, warm years, cold years, years when the bugs produced and years when they didn't produce. And the beauty of these salmonid and resident fish stocks is that they have been adapted to carry on with that kind of uncertainty. And it isn't as we might like to say, can we manage the system to balance the juveniles versus the adults? Because nature is anything but balanced. Nature has lots of oxygen in the gravel one year and kills the fish off somewhere else later. But in this constant flux of environmental change, we have enough diversity and adaptability in the system to make it. So just to bring us back to the thought that the environment is anything but constant, both abiotically and biotically.

Objectives for Carrying Capacity Research

MR. NEITZEL: We are going to start out on the second set of questions, and the first one deals with the objectives of addressing carrying capacity in the Columbia River Basin. And this really leads to the question that Peter Bisson asked of Nora Berwick this morning. I think we'll start off asking Peter to answer his own question. And I don't want to get bogged down in definitions of objective here. Some people call them goals or needs or products or deliverables. What we mean here is, what do you want? If you are going to study or address carrying capacity, what do you want? When you get done with an experiment, a task, or a management activity, what is it that you want? Think of it grammatically, think of it as a noun, something that you could hang onto. And put yourself on the Power Council or the Council staff. Assume that we are going to address carrying capacity. We are going to give some direction to BPA or to the region to address carrying capacity. And this is what we want to see from those efforts.

And after we hear your answers to this question of objectives, we are going to discuss what stands in the way of accomplishing those objectives. What are the critical uncertainties? What will prevent me from getting what I want? And can that uncertainty be resolved? So let's start off with that. Thank you.

MS. COGAN: What do we want? And the audience could be thinking of that, too. Anyone want to get started?

DR. BISSON: I'll take the easy way out and try to give the short answer, which is to use the three words that Lars Mobrand used in his presentation. I think what you want from your experiments is information that will allow you to increase the diversity, productivity, and capacity of the system of interest. In a nutshell, I think that's what you want. You want that information. I don't think that it is possible in most, if not all, cases to do experiments that will tell you what the so-called maximum or optimum levels of those things are. But I think we are mostly all in agreement that we are not anywhere near that stage for any of those three things. So I think that's what you'd like from your experiments.

MS. COGAN: All right. So how do you know when you are there? Anybody?

DR. REISENBICHLER: I would like to dodge that for a second and hit one thing that Pete talked about. Feeling confident that we are nowhere close to carrying capacity now, the question that Nora Berwick posed initially is very intriguing to me. Lloyd Royal (1972) suggested we might be near carrying capacity in the mainstem forest slope migration. -Of course, we had more fish then. There has been some preliminary bioenergetic work. So it just illustrates the complexity of this system. And indeed, focusing on carrying capacity really is putting a heavy burden on the group and the workshop here, I think. But, depending on which part of the system we look at, I'm certainly not confident that we are far below carrying capacity in all regards.

MS. COGAN What information do we want? What do we want to get out here? Increasing the diversity and so on has been mentioned.

DR. WISSMAR: I don't know if it's increasing the diversity/

productivity capacity. You know, that's nice. But we know, like Reg is saying, that probably we've reached the carrying capacity of the mainstem, and that carrying capacity is kind of a bottleneck because it's not what we like. So maybe we want to somehow change the carrying capacity of this middle part of the system between the headwaters and the ocean. So how do we change the carrying capacity of the mainstem? Increase, decrease? How do we do that? That's a loaded question.

DR. COUTANT: I'd like to go back to a suggestion I made yesterday, and that is the comparison between the Hanford Reach stocks and the Snake River stocks of fall chinook. Just take one life strategy at a time with the Hanford stocks, you are doing wonderfully. The numbers are increasing, lots of fish out there. We don't look like we are anywhere near the carrying capacity for fall chinook in the system. Change scene, Snake River. Snake River fish are on the endangered species list. We have what looks like under seeding, in a sense, in some places. We've got fish that are in decline. We look at the Columbia Basin for Snake River fall chinook and we've exceeded carrying capacity. The fish are doing poorly. I guess I would respond to the question posed, that is, how would we address carrying capacity, by asking, what are the components of carrying capacity, however we want to define it, that allow one stock of this fish to do fabulously and another stock to do miserably when they share maybe 80% of the same system? The difference is that the Snake River stock has to make it between Pasco and Lewiston where we have four dams, and the Hanford Reach stock at that point runs into a natural river. So we could perhaps do a better job of addressing what we mean by carrying capacity, and also look for some specifics that will help us restore stocks, if we do a close comparison of those two fall chinook stocks to see what's there and what's missing.

DR. MOBRAND: I agree that we need information, but before we can use information, it seems to me we need a framework, a way of thinking about and incorporating density-related mortality factors in managing the resource. So what I think we need, at the very onset, is to develop a rational framework. Now, people don't want to use models. Really? What a model amounts to is a way of thinking, a way within which we can make decisions that are consistent with our knowledge, uncertain as it may be. I think the first step towards sensible management is to help the scientific process through a scientific framework for understanding this relationship.

The second comment I want to make is that I hear a lot of statements being made here about, we know this and we know that. I don't know that for sure. I don't know, for example, that the capacity is limited to any one segment of the population. I think there are, no doubt, significant moralities that occur lots of places. I don't know if you call that a bottleneck. I think by calling it a bottleneck or referring to it as capacity limiting, we're insinuating that that a problem has to be fixed before any other remedy has any other effect at all. And I don't think that's correct in most cases for things we do in the mainstem. I think our concern is to restore productivity and performance of upriver natural populations, for example. I don't think we have to wait necessarily to solve a capacity problem or remove a bottleneck in the main-stem before that could happen. I think removing bottlenecks would be a critical piece of making that happen, but I think there are many other things that ought to and could be productive as well, So I think we need to be careful about the use of that term and what it implies. It sort of perpetuates, it seems to me, this finger-pointing idea that nothing else matters until this bottleneck is removed, until this limiting factor is taken care of.

MS. COGAN: But where would you start? I mean, you talk about frame-work. You start with a list, or start with number one on the list of information or ways to go?

DR. MOBRAND: I think it's an understanding we are pursuing, and I don't have the answers. I don't know what is first. I can probably sit here like anybody else and come up with my personal wish list. I don't think it would be terribly useful. I don't think it would be something I would want anybody else to pay too much attention to. What I would like to see, and what I think ought to come out of a process like this, is a way of incorporating the historical information that we already have. I haven't analyzed this, and I haven't seen anybody, in fact, analyzing the information that we have in a comprehensive way that looks at the whole life history, as was suggested, the fish's perspective from a full life-history viewpoint. How do mortality factors interplay and how do they interplay with the environment and each other?

DR. PEARCY: Well, I think a major objective here, again, needs to be partitioning critical life-history phases, critical periods, call them bottlenecks, whatever you want, in the various environmental components, starting from upriver, above the dams, below the dams, estuary and ocean. Because until we can partition these survival rates, so to speak, and these different regions, we don't know what's going on in the system. And, obviously, what happens upriver certainly is going to affect survival perhaps in the estuary and the ocean, and that has to be looked at, too. We have to try to partition things and do it over a long enough time period so we can get in the temporal component as well, which certainly is changing from one regime to another.

MS. COGAN: When you say "partition," do you mean to divide them into sections?

DR. PEARCY: Yes. Ideally what you'd like to have, let's say, is the number of smolts released from a hatchery, and then look at the number of fish that survive as you go downstream to the ocean and the number of adults that come back. So you can look at various survival rates and various components over a long enough time period to see where the action is and whether our management decisions in freshwater or hatcheries are having any influence at all. Some would argue that the declines in salmonids now in the Columbia River and elsewhere are showing in hatchery fish that over a very short residence time in a river in estuary that go out in the ocean and then all the action might be in the ocean. This might be the major critical factor since 1976 or so. I think that has to be evaluated in some way. There are certainly freshwater effects, but how important are they, and where are they, and when are they?

MS. COGAN: What else? What other pieces of information? You all are research scientists. You have a blank check. What do you want to do?

DR. WISSMAR: I think we have to step back and say, okay, we have a problem in the Columbia. And part of that problem is because everything we do as human beings is for the control of natural systems. Obviously, dams are a form of control. We are working against how the natural systems operate. And they operate on different regimes, so there is a certain amount of instability in these systems. Well, we try to control that; we are taking that away. When you do that, the biology has evolved to the changing systems. And as they have always changed and they always will with different scales. For scientists to do anything with the natural system, we've got to be able to bring some of these natural physical and biological cycles back into play. Can we have the luxury, since you have given me a blank ticket, to work, say, with the variable regime as far as hatcheries, variable flow regimes as far as the dams. Can we reintroduce some of these natural physical and biological cycles into the system? This will give us the capacity to do experiments, Right now we are locked in by the mindset of modern man, which is to control, control, control and put balance, balance, balance into these systems. And for scientists to really behave in the proper arena, we need to be able to work with the changes in these systems, both biological and physical.

MS. COGAN: Anyone want to add to that? Does that make sense, that somehow if there is a natural system, there are highs and lows, and what counsel do you give to the Power Council and BPA to deal with those?

DR. WISSMAR: There's got to be a certain amount, I would say, of plasticity in management and the laws to be able to do some new type of manipulation experiments at different scales, biologically and physically.

MS. COGAN: I don't know if either of our representatives want to reply to that or give us their perception, but that would be helpful. How much elasticity can you afford, can a public agency actually handle year-to-year or every two years or whatever the cycle is? I won't put you on the spot, but if you want to get in here, we'd like to hear from you.

MS. BERWICK: I, first of all, want to make a comment getting back to the original question, and then I will get to what you just said, because I have some thoughts on that. Looking at the question of what should be the objective of addressing carrying capacity, putting it to you panelists, would you not think that the overriding objective might be increasing the survival of salmonids in the system? I mean, is that an overriding objective?

DR. MOBRAND: I'm wondering about that sort of unbounded objective. You know, maybe our problem isn't carrying capacity. Maybe our problem is our expectation of the system. And so it seems to me that for an objective on salmonids, there must be an end to this. There is a place where we meet. And survival, it seems to me, who cares about survival? Fish care about survival. But in society, who cares about survival? What you care about are some other tangible things more leading to value, I guess. And unless those are somehow bounded, I don't know how you can solve the problem. To me the problem, otherwise, is unbounded. There is never an end to improving survival, for example.

MS. BERWICK: We do seem to be having some problem with survival right now. The numbers are going down. How do we turn that around? And does carrying capacity have anything to do with turning those numbers around so that the graphs don't show the slope going down, down, down to --

DR. WISSMAR: It certainly does have different survival rates for different life stages. We don't have many good estimates of survival rates for different life-history stages within different stocks. I mentioned yesterday we apply numbers of egg-to-fry survival generated in the Yakima to the Methow. We may be plus or minus 200% there as far as what is happening. And that's just for one little piece of the life cycle for one stock. So survival is important. If you want to put a lot of money into that basket, that's fine, but in the long run, it may not get you anyplace given the magnitude of this problem. You are going to have some different types of thinking than we've had historically, which focused in on survival and so on.

DR. BISSON: I think your question -- isn't it a good objective to increase survival? -- has at least two parts and maybe more. To a scientist, this might lead to the question, what can we do in the short term to increase the survival of the cohort of fish? But also someone like Reg might ask the question, what can be done to increase the survival of the species? They might lead to different answers. Evolutionary survival, and the strategy that you would try, and the information that you need to try to get evolutionary survival, might be somewhat different than a strategy that you would adopt to keep the survival as high as you could. Each year you manage the system in a certain way.

MS. BERWICK: And that's what I'm hoping, that by my asking the question, we can maybe get to that. It seems to me, from what I've heard and from what I understand of the system and how it works, it's a combination of a couple of things: You need to have the genetic variability in all of the populations, and you would have to move toward doing something that would tweak -- well, I shouldn't use the word "tweak" -- somehow do something. The question should be, is there anything we can do about the carrying capacity, or those factors determining carrying capacity, that would allow for the different stocks to have the resilience that they have had in the past when there were many events that required resilience to survive.

It's a two-part thing. You have to take care of the habitat. You also would have to take care of the stocks, to be sure you got the most resilient stocks. But, again, it's not the bottom question, looking at turning around these curves, showing just, you know, the decrease in survival down to nothing so there are no stocks at all. I mean, is that what we're looking for? I don't think so.

MS. COGAN: You're saying that's the reality today --

MS. BERWICK: Yes.

MS. COGAN: -- and what are we going to do about it.

MS. BERWICK: Yes.

MS. COGAN: So we've said we don't want any finite numbers, but on the other hand, we know what the numbers are telling us.

MS. BERWICK: Yes.

DR. BOTTOM: In all these cases we're dancing around the values here as to what we want still, what we're asking to create. Are we asking to see what is the most we can get out of the system, given that we are going to have all the dams and we are going to continue hatchery production at a certain level, or tweak the existing system? And to do what? Is it to make sure that the species don't go extinct, or to maintain a ceremonial fishery, or to maintain productive fisheries throughout time at something approximating their historical level? And then we can say, the system as it is now either can or cannot be tweaked to do that. I don't know if we can say that with certainty, but we certainly have lots of information to suggest that we are going to be hard-pressed to reach historical levels of production as the system now stands today. I don't know if anyone here would suggest we do that.

MS. BERWICK: That sort of moves back to exactly what you were saying.

DR. WISSMAR: Given the rigid controls we put on the system as man, the scientists need to have an objective. How do we put genetic and environmental variability back into the system?

MS. BERWICK: Right.

DR. WISSMAR: Can we be allowed to do that within all the legal and other constraints that are on the system?

DR. SIMENSTAD: To me this broaches a fairly philosophical but also critical issue about ecosystem management. And I think there is quite a potential dichotomy here between the concept of managing an ecosystem to get what we want out of it versus managing our activities to try to optimize natural processes. And I would suggest that what we need to do is what Dan talked about, which is to look at ways we can potentially increase the realized capacity which is far, far below potential. But to acknowledge that, we can't manipulate bottlenecks. We can't manipulate the stocks. We can't take advantage of "windows of opportunity," because we don't have that latitude. We cannot manage the system. We cannot manage ocean regime shifts. So what we need to do is build back in the resilience of the population to handle our alterations of the system. And most of these alterations are those which cannot be changed in a major way.

MS. BERWICK: I want to speak to that. I think that everybody is saying the same thing, essentially. There are some choices that have been made, and those choices were to put up dams and maybe not pay attention to the tribal fishery. And what I heard, what I think you were saying, is that we can't just talk about survival, because it's survival of what? And it all gets back to choices that have been made on our part to do things one way or the other. And what we are trying to get at here is, how do we make more choices as to what we can do? We can't do it all. We can't have the dams and have the tribal fisheries, and have hatcheries way up high in production and have a lot of pollutants in the water. What is it that we need to do to maximize what we want? Maybe we don't want any salmon.

MS. COGAN Because what we are hearing is that we are not sure what we want.

MS. BERWICK: That's right.

MS. COGAN: I think that's what they're saying.

MS. BERWICK: Yes.

DR. WISSMAR: You are asking the scientists to tell you what we want, which has been pretty irrelevant up to today. I can tell you what I want, but I don't know that it means a hill of beans in terms of what society wants or what the Power Planning Council wants or what someone else would want. There is a value system in place, and it's assumed, I think, in all of this discussion, based on whatever anyone who is talking happens to think we are trying to balance.

MR. NEITZEL: I would like to add a thought there. That maybe it is not the job of the scientist or the technical person to tell people, this is what we want or this is what you should want. Maybe our job is to tell the public and decision makers that, if you want this, this is the possible outcome. These are the possible futures from your actions, from your lists of wants. And if you are going to operate the system for power, this is the possible outcome. If you are going to operate the system to protect endangered species, these are the possible outcomes. To get back to these questions of values that were in the model that Lars Mobrand showed us, that values box is relative to performance and whatever actions. And you as an expert panel can say, here is the possible outcome of what you want, rather than saying, this is what you should want.

MS. COGAN: That's very relevant, Duane. And we have heard Nora Berwick say that increased survival is a want, or at least is an objective.

MR. ROGER: Phil Roger, Columbia River Inter-Tribal Fish Commission. Let me propose a little structure that maybe will help you people answer some of our questions. I think society has set some goals. The ESA has maintained population to stop this decline that's going on. That's one goal. The Power Council in its 1987 program had a goal of approximately 4 million salmon above Bonneville Dam. It was phrased a little differently than that, So, let's say, first we want you to halt the decline and preserve our natural production that's existing now. Second, we want to achieve this 4 million fish above Bonneville, and we want to do it with natural fish. Let's take hatcheries off the table for a moment. How would you advise us to go about doing that, and what are the trade-off points?

I agree with Bill Pearcy, let's assume we have a monitoring system in place that can measure survival at each major life stage so we know what's happening in the tributaries, we know what's happening in the mainstem, and by subtraction or maybe monitoring, we know what happens in the estuary, and then we see the returning adults. Within that framework, what would you advise us to do?

MS. COGAN: And are you saying that's the political reality of today?

MR. ROGER: Yes.

MS. COGAN: As good a framework as any, I guess.

DR. BISSON: I would like to make a suggestion, and probably alienate myself from everybody else on the panel here and most of the audience. But how about this for an idea: Abandon the stock concept as a basic unit of salmon management. And here is why: I think it's too big. I think that if, in fact, we want to get this information on population survival for any other measure of success at successive stages of the life cycle, probably what we are going to do is go out there and look at the main spawning site and the main rearing site and the main over wintering site and the main migration corridor of that "stock," and we are going to miss what's going on in the peripheral deeds. I think that is a big mistake. Just as I think that for ESA purposes, the "evolutionarily significant unit" concept may be an appropriate way of classifying, organizing the thing in terms of the goal of conserving genetic diversity. It's way too big, I think. I really do.

So I suggest, for example, if we want to develop information on how we can ensure long-term survival of salmon, that we start to wean ourselves away from the stock concept, that is, as it is currently being operationally applied. Because I think it's too coarse-grained. I think we are going to have to look at more fine-grained population structure and ecology. So I will toss that out to some of the other people on the panel.

DR. REISENBICHLER: It's probably a bit of semantics, Pete. I don't think we need to toss out the stock concept. I'll hit on that in a second. We certainly need to recognize the importance, again, for about the 100th time, of diversity versus life-history types and genus types within those stocks. And I will just toss this out, it's probably completely off base. But I think the way to approach this, the questions that Phil brought up, or at least his focus, is to basically do what Chuck Coutant and Lars Mobrand have been talking about in a sense. That is, identify some of these high-priority stocks. For whatever reason, the Snake River fall chinook is clearly a high-priority stock for ESA reasons, for one thing. Some of the other stocks go through this patient-template analysis that Lars and his colleagues have been developing, follow that all the way through the life history, again, one of the other aspects that has come up. That way we hit every part of the system.

And that kind of analysis includes just comparing the Fraser system to the Columbia system. It really, in a sense, is ridiculous to propose. It's very big, it's not the simple thing you're looking at. But piecemeal with the stock concept, again recognizing the importance of diversity within that -- of course Lars knows the fish template much better than I do. But I really think that's the way to go. I think by focusing on carrying capacity alone, we're really pushing ourselves into a corner, just making this harder to approach. With one of the specific problems you mentioned -- and carrying capacity, it seems to me, is a highly relevant question -- if you are worried about not making things worse with your hatchery program, how many hatchery smolts can you dump into the mainstem Columbia River that will fall out with this patient-template analysis of stock? It certainly could be addressed as a separate question.

DR. WISSMAR: Just to add to that, you also need to go through that procedure to make sure you secure some nice healthy stocks and healthy river basins so you have something for the future. Why are they self-sustaining and in good shape? You've got to know that, and in many cases we don't. So there is that side of the equation also, as far as the endangered side.

DR. REISENBICHLER: I think part of this is just that there are two levels of this patient-template analysis. One is to prevent further harm being done by some other management actions, and the other is some recovery-type goal. So the patient-template analysis, it seems to me, includes it all if we simply go with it all the way. And, again, that's from diversity within stocks all the way out to the ocean.

DR. WISSMAR: We need some landscape information on how land uses influence these systems. And the template does not necessarily include that, except probably the historic component that it recommends.

DR. MCCULLOUGH: In some ways I would disagree with Pete's approach, that we need to manage on this system level. I think that the ESU level itself is quite fine. I mean, it pertains, as it's interpreted, to river basins of a fairly small size. On the other hand, I appreciate what he is saying, because I think there are differences in streams within river basins that need to be protected. But we have lost so many of the life-history expressions that are possible in the populations, that we probably don't even know anymore what units we really have to manage as far as fish But one thing we could do in managing what we have left is to undertake some of these experiments like Chuck Coutant and Bob Wissmar were alluding to. Say, for freshwater habitat if we really restore an entire drainage basin from the headwaters down to the mouth, say, the Grand Ronde. Not just tweak the system like we have been doing, like backing off on cattle grazing in riparian areas by 5%. That's not going to result in habitat restoration. We need to open up the rearing areas in the mainstem Grand Ronde that are no longer usable because they are too warm. The life histories within, say, the spring chinook that used to exist in the system probably include components that used those lower river areas.

And so I think we would find that, even though we don't have visible populations that are managed now, the genetic capacity would re-express itself if we restored the habitats. And we'd find that we could in the future have spring chinook that would spawn lower in the system, higher in the system, and fully utilize the habitats if we really restored it.

MS. COGAN: So you would meet their goals, but through the means that you're suggesting?

DR. MCCULLOUGH: Through an emphasis on habitat restoration rather than trying to identify something like ESUs right now, and try to direct our management towards those, because that may not be really the best of what we have to manage in the future.

DR. GIORGI: Al Giorgi, with Don Chapman Consultants. I want to pose a different objective, if you will, and then maybe throw out a couple of examples. It seems to me that one of the primary objectives here is to deter-mine to what extent our management actions have maybe overtaxed carrying capacity at some critical life stages of the salmonids in this system, and particularly relative to the impact that it could have on the performance of wild stocks. And as an example, I would like you to consider the sort of management activity we have, the hatchery practice in the upper Snake River Basin where we release tens of millions of fish virtually simultaneously in the drainage. And we release them at such a point in their development where they are not really ready to initiate their migration. So they maintain residence for some period of time in the upper drainage. And you have an accumulation, then, of a massive population of organisms that is collecting in this upper pool. And then we are staging an operation at Granite Dam where we have a chief juncture there for transportation and/or bypass, depending on your mode of passage. And we are forcing this huge population, then, to encounter these constricted conditions. And we are expecting that this population is going to perform in some fashion that just isn't consistent with what our expectations should be. That we are expecting more from them than we should. And another example that comes to mind is the fact that --

MS. COGAN: And what's the consequence of this action?

DR. GIORGI: That's what I'm posing here. It seems to me that we are confronted with maybe not learning so much about what carrying capacity is, but certainly with looking, taking a commonsense approach, and seeing if this makes sense in terms of what we would suspect. And, if there are studies that we need to alleviate fears or concerns, that, in fact, this procedure is not having a deleterious effect on either the hatchery population or the wild stocks that are intermingling with it at this key juncture. Another practice that we permitted over the years is the infusion of shad into the system. And I say that we should permit it, because there probably are steps we could take, or may have taken in the past, to prevent it. But we have allowed an exotic species to come into the system and establish itself quite successfully. We really don't understand how that species has changed the food web structure and interactions with the salmonids. And personally, I don't care if we can define the carrying capacity of any particular system here, but we've got to deal with how we manage around it and make sure we are not overtaxing this capacity at critical points, just by foolish actions.

MS. COGAN: We dealt with some of that yesterday and we are skirting around it today. Anyone want to answer or give any comments on it?

DR. REISENBICHLER: No answer, but a comment. Just that I agree with you 100% that sticking to a carrying capacity thrust might well miss some of these problems you're talking about. I think that rigorous patient-template analysis would focus on some of these issues that you've identified as part of the problem. I think your specific problems would be addressed in this kind of approach to the overall ecosystem and salmon problem in the Columbia system.

MS. COGAN Let's move on to the next part of the question, that is, whatever carrying capacity,is or isn't, and I don't think we are going to get to that definition today, what stands in the way of meeting our objectives? We have talked about natural, unnatural, dams, etc. How would you answer that second part of the question? What's in the way?

DR. WISSMAR: You know, how much plasticity do we have in the management system to actually look at some alternative release strategies and so on? Is there plasticity in that system for science to come in and work with the hatchery system and try to look at some of these practical solutions, which would maybe involve alternative release strategies as far as number, size of fish, and timing.

DR. GIORGI: The experimentation that takes on the scale you probably need to conduct it, doesn't really occur. It's a lot of small-scale hatchery studies that have occurred here and there throughout the system. But I guess my question is, it seems plausible that you could be overtaxing the capacity of the Lower Granite Pool where you're losing 20 million smolts in the river that are not really ready to leave anyway. We are going to be looking for resource estuaries that may not be there because we have a diminished capacity in that reservoir.

DR. WISSMAR: Yes, I understand that. But do we have the power and the system to work with what's happening as far as the hatcheries to make some changes to answer some of your questions? Like maybe release different sizes, numbers, or timing of the fish. You know, have these different scenarios as experiments.

MS. COGAN: Are you asking, what flexibility is there in the system today?

DR. WISSMAR: It sounds like there is not very much flexibility in terms of the release of fish.

DR. GIORGI: There hasn't been to date, and unless somebody calls for it, there won't be.

DR. WISSMAR: So there's potentially a role for science to play, and you could do some type of experiment with the managers. Like I said, we are getting into genetic and environmental variability here. Here's a way to come in and work in the system.

MS. COGAN One of the problems now might be the inflexibility of the system, or seeming inflexibility.

DR. WISSMAR: That's man's side of it, we are not very flexible.

MS. COGAN: We haven't been to date.

DR. MOBRAND: I will just repeat myself a little bit. I think, again, what's missing is a framework. Al Giorgi probably presented it right. What we have is really a menu of things that we might want to do, ideas. To ask a panel to come up, out of the blue, with suggestions without any practical sense doesn't make a whole lot of sense. What we need to provide, I think, is the tool or framework which can prioritize those, comment on those types or suggestions, and rank or analyze them. Here are the tradeoffs, the benefits and risks associated with those things. And that requires a tool or a framework where you can comment or say something sensible about potential actions.

No action is going to be uniformly beneficial to all intents and to all purposes. So it's going to need tradeoffs. But a tool or mechanism or framework for addressing, I mean, it's the classic problem. You know, what the region struggles with is prioritizing its resources. Where do we spend our money? We don't have a way of ranking or classifying or commenting on the value or benefits that come out of these risks, that arise out of these kinds of proposals. If we did, we may be able to overcome a whole lot of inflexibility, I would think, on the leverage of funding.

MS. COGAN: But we've been told that one of the Power Council's objectives is increasing the stock. To paraphrase you, I think that is what we have been told since the 1980s. Right? Is that part of a framework?

DR. MOBRAND: No. I'll ask the question, does this make sense, and how does it fit within a framework of priorities? Is this the sort of thing we ought to be doing? And I'm suggesting a scientific framework and understanding of how the abundance and capacity and dynamics of the mainstem Columbia, freshwater and the ocean, allows us to comment on or prioritize those kinds of proposals.

MS. COGAN: What else is in the way?

DR. COUTANT: I have a bit of a framework for Lars. And it goes back to something that Pete suggested about looking at things in a little more detail. One of the conceptual frameworks that we have right now, and he mentioned it, is that if we provide the best conditions for the most fish, then we will have the best returns of fish, the average condition. And I'd offer as a contrast to that what folks have been looking at in various places around the country, and that is called the individual base model. It's a very different way of looking at how the world works. And some of the work I did with largemouth bass may not be terribly relevant to salmon, but if you took a population or a batch of largemouth bass, put them in a pond or a tank and fed them all they'd eat, what you'd get is a lot of relatively small largemouth bass, none of which would do terribly well.

If you take a batch of fish and not feed them very well, what you'd get is what we call jumpers. Out of that hundred bass that you started with, they would eat each other up and you wound up with a bimodel distribution of fish. You had a bunch of them that stayed small until they were eaten. But you had another batch of them that suddenly, bang, they took off and grew. And some other folks have looked at largemouth bass dynamics in reservoirs, and it turns out that the ones that count for keeping largemouth bass populations going in reservoirs are the jumpers. It's those few fish that make fast growth rapidly in the season. They wind up being the ones that survive in the population. So that's just one example of looking at the growth survival not in terms of the average across the population but in terms of what happens to a key bunch of them -- in the case of largemouth bass, those few that are jumpers -- and following those through, you can get a better handle on defining what the system is doing.

Individual base modelers can use computing techniques to follow individuals through population-dynamics changes and simulate things like that jumping phenomenon. And it may very well be that if we were to take a conceptual-framework jump in large context and try to model what happens on an individual basis with these fish, we might get a better handle on survival, mortality, returns, and things like that. At the moment, I'm not coming up with a specific way to do that or which ones to actually look at. If we were to start thinking in terms of individual dynamics, fine scale, as Pete Bisson suggests, and run our models on that basis, we might come up with some very different conclusions than by doing things in the aggregate and the average, as Lars has talked about before.

DR. BOTTOM: There is a difference. There are two approaches that I think can go on simultaneously. One is the research end that causes us to ask those kinds of questions that are fairly detailed. And the other is, what do you do in the meantime? Are there things you can do in the meantime to minimize your risk and increase your options in the future? And I think it's in that latter case with all the things we've talked about in the last day, the things that can be done on the basic principle of maintaining as much diversity in the system as possible to the extent that we know it. And maybe do some things that we think would have that value of minimizing risk and increasing options, even when we don't know all the details of that diversity, even if we don't know all these individual stocks, even if we don't know all these differences.

There are some basics that will take care of lots of things and carry them with them at the same time. For example, many landscape kinds of strategies that people are proposing are based on looking at the landscape and how it's arrayed. What looks different? How do we compare things and say that this watershed behaves differently from that one because it basically has a different geology and different vegetation, different soils. And maybe we don't know all the stocks that are in that watershed, but we might infer that they have a potential for being different from stocks in another watershed that is fed by snow-melt as opposed to rainfall, or those sorts of things. And so when it comes to setting up protection or restoration strategies, we try to array them on the landscape that catches the greatest amount of diversity as possible. And in terms of protection, one thing that we know today is that if we were to do a protection strategy, we'd be up in the headwaters in a lot of cases. Those are important areas to get control of as best we can now because of their downstream effects, but we also know that they are not the areas that are historically most productive. So the question, then, is, how do you expect to build off of those to get down into some of the more productive habitats, and how are they arrayed on the landscape? And so where do you set your priorities there?

So in terms of habitat, I think there is no question that we can do a lot of things on the basis of what we know right now, or at least we can suggest lots of things. Then it comes down to whether people are willing to do them. Are people willing to either fence cattle or make the changes in how ranches are managed to get that effect or not? Are people willing to change irrigation practices in order to move that wedge of cold water downstream from the headwaters to where it would be effective? You know, we could draw a map probably right now just on the basis of water temperature in the Columbia Basin. And it becomes pretty clear that the carrying capacity of that system has been marginalized just on the basis of where fish can occur. So that we could do without a whole lot of research right now and perhaps make a difference.

MS. COGAN: So far we have at least two things that are standing in the way: One is the lack of a framework for decision-making or even for offering research. And the second one I'm hearing is the willingness or unwillingness of people, individual communities, to change habits.

DR. BOTTOM: That's part of the reason I asked the question there. I didn't mean to belabor that. But what we really want is, we want it all, and that is the problem. And the reason I raise that question is that we probably can't have it all. And then it comes down to people like us to raise the red flags and say, you can't have it all and here's why and here's what science says about it. And it becomes kind of a football. But at least, by making comparisons to history, by making comparisons spatially, we can point out where things have fallen down. And that's, I think, an important role that we can play.

But then it comes down to the hard choice of whether or not you are going to do anything about it. And I think there are lots of things on the table right now that at least could put some resilience back in the system, probably raise some productivity in the system, that are not being acted upon.

MS. COGAN: What else is in the way of acting?

MR. ASKERN: Just an observation about flexibility, ability to do things on an in-season, yearly basis as well as multiple years. The biological opinion for this year, for 1995, as well as for the next three or four years for hydro-system operations does some of the things you've alluded to. It allows for testing a particular hypothesis, for example, a biasing of your operations. In this case it was biased towards a particular regime of transportation. But it also sidestepped the intent to try to keep conditions constant so you could evaluate the effect of transportation. It sidestepped it, in a sense, by having some conflicts in how you were actually managing the hydrosystem. One requirement was that you're supposed to try to replicate or duplicate a natural hydrosystem, whatever that is. But it also required that you make certain flow charts, flow averages, or whatever that was, in a couple of different projects.

So we had an intent to evaluate some parameter or some operation, and people willingly did that. But you also had some conflicting legal operation requirements in that opinion. So will we be able to actually assess the effect of transportation given some conflicting flow requirements? The point being that there are legal requirements out there that determine how we can evaluate many different things including carrying capacity, whatever that is. We can do those extreme operations if you can convince the management structure to commit to those in writing each year. But be aware that there is a natural tendency by the managers to stand on the fence. Whenever there is doubt, and there is a lot of doubt in all of this, they will preferentially stand on the fence and try to do both things at once. And in that case, you may or may not have enough control over your system, monitoring evaluation, and the like, to actually come out in five years or so and say "yes" or "no." We have vehicles to do the work, but we need, as a group, to look very carefully at what those documents actually end up being so that they can produce results.

MS. COGAN: So some legal requirements are another impediment and maybe a political reality?

DR. BOTTOM: I guess this echoes Lars Mobrand's conceptual idea, but I had the opportunity to review the NMFS recovery plan for upper river salmon. In my opinion, it was a classic case of that problem, of the lack of a conceptual framework. Because it started with the existing management system, and there is a section on each of those parts of the system: there's a section on hatchery, there's a section on dams, there's a section on harvesting. And that's one way to approach the world. Here's the template, okay, and how do we manipulate it?

What was lacking in the ability to evaluate what any of those manipulations meant was an overall description of the system, how it came to be organized as it was historically and how it is today. What was it that caused it to organize itself biologically the way it did and to function the way it did, or at least how do we think it did? So that when you have some context for thinking, as a consequence of that evolutionary link between habitat and life history, or between the organization of biological assemblages or between flow regimes, whatever that concept was, that it explains the patterns of variation in the natural system, and as a result of that, here's why we chose these actions. If you don't have that up front, then what you have is a laundry list of actions hanging out in space. Oftentimes there is a rationale, but they are all individual, and they are mutually exclusive. They are not complementary in any way because they are based on some ideas that are by themselves, or they are not explicit, as was our economic view. We had a conceptual framework; it wasn't always very explicit, and it doesn't seem to be a very adequate one.

So I would argue that the conceptual framework we need to develop should be an evolutionary one. And that it should focus on the development of explaining variation in natural systems, on how variation structures those systems, and how it causes biological systems to organize. And then from that, develop some ideas on the implications of that, of how and what we might do to mimic, or come close to mimicking, natural systems

DR. MOBRAND: Just a couple of comments on the framework. I think part of what needs to be done is to facilitate discussion about carrying capacity and other things. But it also should be a discussion that doesn't restrain different viewpoints, because there is a great deal of uncertainty. And a good framework ought to accommodate and clarify those differences as opposed to forced agreement where there isn't any. So a framework isn't necessarily an attempt to drive everybody to think one way, but to communicate the same way.

MS. COGAN: And I think that's what we are trying to do here. At the end of the day, we could have said, "You can't leave until you get to a consensus." But I think we don't dare do that.

DR. SIMENSTAD: I think one of the advantages of a conceptual framework is to examine the scope of our opportunity. If we a take a look, from my perspective, at the estuary, we have a certain number of opportunities, and we have a certain number of things we know we can't change. We are not going to be able to alter the presence and probably the role of exotic species in the system now. The system is greatly de-energized from the way it was historically. I mean, it's an estuary on Prozac now compared to what it used to be like. We are not going to be able to reverse that to a large degree.

On the other hand, the system is diminished by habitat loss which, to a large degree, is reversible. And the framework could help us identify the contingencies. Reversing some of that habitat loss through restoration won't do a lot of good, because that habitat is going to benefit mostly subyearling fry portions of stocks and races. And it's not going to do any good if there isn't concomitant response from the standpoint of intensifying or enhancing those portions of the stocks that utilize the estuary. We are probably far below carrying capacity now for those portions of stocks. Enhancement isn't going to do any good without a framework to guide us in how we can optimize the potential for utilization, because right now we are shunting most of our fish through as yearlings or smolts, which really isn't taking advantage of what we could restore further.

MS. BERWICK: I have a question for Dan Bottom. You said a few minutes ago that there were a whole host of items you felt you could come up with. That would mean we could address some management actions and make some things happen that would increase the diversity of the system toward what we were talking about before. By the same token, I'm hearing also that we need to have a framework, otherwise you're operating in the absence of holding the whole operation together here. But would you feel comfortable, in the absence of a framework, coming up with a list of -- I don't want it to be a laundry list. Is there some way of coming up with some sort of framework such that we could get at what you think are the critical research needs and the management actions that could be done without doing research for ten years before making a decision to act?

MS. COGAN: That's fair. And we're going to ask you to think about that at lunch time, so you don't have to do that right now. That really is our charge this afternoon.

MR. THOMS: Andy Thorns, BPA. Dan, you made mention of these farmers being able to send the cold-level water downstream. I have managed a lot of habitat projects. What your farmers are interested in, basically, is not the fish. They are interested in their crop or their production of cattle. The key to getting them on board is keeping their land. When you have flood events and you've restored the stream habitat-wise, you've protected their land, they'll be thankful. But it also gets us the fish that we want and the habitat that we need. I think we also need to think about the realities of what other people need while we get what we need. I think it's fair to say we want that cold slug of water, and we want that habitat.

DR. BOTTOM: And I don't know whether biologists have done a very good job -- probably not -- in trying to communicate some of the values that might do double-duty, if you will, in riparian systems for example.

DR. THOMS: Another thing, we had other farmers who were dealing with a tremendous number of moles and voles eating their grain; you know, mice. And one thing we proposed was to put 55-gallon drums with barrels and sticks on the top where you could have your hawks and owls migrate in and reduce your populations. It cost them almost nothing to do that. When they found out the effectiveness of it, everybody jumped on board. But until you get to that point, so they understand that, you may lose some trees here or some stream riparian areas alongside that *(unintelligible)*. Until you get to that point, then, you don't get any reaction or action.

Only when you get flood events or something like that where you lose tremendous amounts of land or crops. And DEQ was on board this spring when 15Mile Creek let loose, and we not only had loss of croplands and fences, we also had other things to deal with like 24D in the system, Oration (?) in the system, and cans ready to go off as many little mini bombs.

MS. COGAN: And what you are suggesting is that whole management aspect of it. And it has as many parts as everything else we have been doing and talking about.

Specific Research Needs

MR. NEITZEL: This afternoon we are going to the third set of questions on the agenda, and they deal with the research needed to improve survival. What research can we do right now? What needs to be done first? And then we want to get into what management actions can be taken now and in the long term relative to carrying capacity and to the improvement of salmon survival. And then deal with the monitoring question relative to the elements we've talked about here the last two days. Can we monitor to evaluate our management actions? If an action is taken, how do we know whether it's doing what we set out to do? After that, before we adjourn, we are going to ask the panel to summarize their thoughts and to say one parting thought on what they would tell the Council staff that should be done relative to carrying capacity.. And then we will end up with some comments from the audience, but mainly we will give the panel an opportunity at the end to summarize their feelings.

MS. COGAN: It's really carrying forth the discussion we had this morning, but to another level. Now we are talking about managing it. Now we are talking about getting where we want to go. And there have been a great many comments about the need for a framework for decision-making and for whatever action we need.

DR. WISSMAR: I hope somehow you'll let the scientists through the door so that we can test some concepts that touch on carrying capacity. Things like manipulation of hatchery releases in different parts of the Columbia River Basin, ocean-type stocks versus stream-type stocks. And when we do this, we get into having the freedom to work with variable-release strategies relative to timing, fish size, fish density. Ten years ago, Si and I talked about our dreams of doing work on carrying capacity in estuaries. Let's do it in the estuaries, let's do it in the mainstem, and let's do it in the tributaries, if we can. Because when we do this, we can also couple it with some habitat and system restoration in some of these systems that still have some resiliency left in them.

We can also do the same thing in systems that may be somewhat damaged. And we are experimentally using the hatcheries to set up different scenarios, fish releases, sizes, and density, in habitats that are in different stages of conditions. Because you've got to remember, everything is changing, nothing is static out there in the physical and biological world. We're the ones that make things static. We're the ones that like equilibrium in the world. And to get any of these fish back and any kind of recovery in the system, we've got to bring back this environmental variability. And with the hatcheries, we can bring in some genetic variability, and you could get a team of scientists here working together in different parts of the Basin.

MS. COGAN: As we said this morning, we know what carrying capacity isn't. It isn't a finite number, but it has many, many different parts. What research do we need to do and in what priority? What would you do first if you were given the time and effort?

DR. SIMENSTAD: I'll start out with probably what most people expect me to talk about, information needs. But I'd like to mention something that actually is a retrospective examination, in some respects, of old data. There is a phenomenal amount of information embedded in scale information. And there is a lot of scale information sitting in agency drawers; specifically, composition by life-history type of a variety of stocks. Most of Paul Reimers' work was done on scale analysis. And it seems to me that many hypotheses can be tested initially simply by expanding a lot of those retrospective analyses to existing information. I don't know what specific systems have the best data, so I can't make that sort of recommendation. But I think specifically looking at long-term trends and life-history-type composition, particularly of chinook stocks, could allow us to at least develop an initial conceptual model of how diverse these stocks are and how they respond not only to environmental variability but also to our changes in the system.

And one of my points gets at what Bill Pearcy was talking about in terms of understanding mechanisms. I think for most of us on the panel here, all the correlations in the world still aren't going to get us to the point of making management decisions, which I think requires mechanistic understanding.

MS. COGAN: And Robert is saying the same thing in a way, that we have to look over time and be cognizant of the fact that nature is not static and probably isn't as organized as we think it is. What else? What other priorities? How would you answer that question, what needs to be done next, tomorrow?

DR. BOTTOM: A continuation on that theme, I guess, whether it's scales or the field work associated with the same idea, is that a lot of what we've talked about here the last two days has hinged on the notion of this diversity of strategies that has evolved out there to take advantage of whatever diversity exists in the variability of the natural world. I think we may learn a lot through doing comparative kinds of approaches where we can't get long-time series of data because of the expense or the inability to maintain research projects for a long time. There may be places where we can trade space for time and take comparative approaches into how different stocks have evolved or are adapted to different types of environments. Trying to draw that link between life-history type and habitats where those fish occur.

And one reason I bring this up is that I think one of the conceptual problems we face in these kinds of management issues is that we have compartmentalized our knowledge, particularly in applied sciences, according to the way we manage things. And so we've had habitat biologists working for the land management agencies managing habitat. We have fishery biologists looking at stock-recruitment curves and managing fisheries. And we haven't done a very effective job of bringing those things together. We had some pretty good starts on that back in the 1920's and '30s. People like Willis Rich (1920, 1939), who was beginning to see the diversity of life-history types in the Columbia way back then. And if we had acted on that knowledge in the '20s and '30s we would have done things a lot differently and wouldn't be here today trying to figure out how to undo some of them.

So I just think that this patient-template idea -- correct me if I am wrong -- is a conceptual framework that hits right at the heart of this. It makes that bridge between the way life histories are organized in a stock, which is an expression of both genetics and environment, and how the environment and variability are arrayed across the landscape and may be responsible for those adaptations.

You can take that a step further, then, and maybe look at which life history types are doing well and which ones are doing poorly. If we had that information, we might be able to draw some inferences as to causal factors and why we are losing some of the diversity and productivity, and that might help us decide some priorities as to where to work.

MS. COGAN: What else? What other priorities?

DR. MOBRAND: Just to add to that. To understand the historic life-history patterns, you'd want to do some environmental reconstruction, to the extent that's possible.

MS. COGAN: Why wouldn't it be possible? What are the impediments?

DR. MOBRAND: I don't know exactly how one would go about doing that. There may be archives, maybe documentation in various places that capture some of that. I don't know where it is.

MS. COGAN: Give us an example of what you're talking about.

DR. MOBRAND: Informational goal temperatures, the physical parameters that describe where to find them, the mainstem Columbia in the estuary.

DR. BOTTOM: Some of the best information I think that we've had to deal with any of these problems has been from those biologists who've bothered to do that. I think Jim Sedell's work on the role of woody debris in a system is an example of that. As a result of that kind of work, we haven't totally changed our idea about what constitutes good habitat in fish. There has been a revolution in that. And that was based on old anecdotal accounts and documents such as Corps reports that were collected for totally different reasons. And I know Bob Wissmar has done work on historical reconstruction in the upper Columbia, trying to recreate what habitats looked like a century ago. Not that we will ever, necessarily, be able to go back to what it was 150 years ago. But that we have some idea of what it looked like so we know what is possible and what kind of direction we might want to move toward. So, yes, I think that's critical.

MS. COGAN: What else? What other research needs do we have?

DR. MOBRAND: Again, addressing the diversity issue, I think we attempt to manage the Columbia on the basis of the central 80% of the outmigration. I think we have a better understanding of some of the tails Dan was suggesting, some of the broader use historically of the mainstem on the estuary. Maybe some of those populations, the few that are still out there in the tails, maybe they can tell us something. Their survival and performance, perhaps, outside of the Columbia Basin may be critical. We may be managing the wrong portion of the run.

MS. COGAN: Someone suggested this morning that we study the Fraser River and how well it's doing. Is that something that would be appropriate?

DR. SIMENSTAD: I think that's an extension of Dan Bottom's recommendation of intrasystem comparisons, but also inter-system comparison.

DR. MCCULLOUGH: I think there would be a good opportunity to get a good picture of the state of the habitat throughout the Columbia basin. And there have been some proposals for doing that. There is a lot of information in various agency databases. It's not all put together in a comprehensive system. We could apply GIS technology to map out the conditions in order to acquire some of that information rapidly. People now are using thermal radiography to fly over streams, say, during the summer. You get a real detailed picture of the water temperatures. And you could really see how many streams are providing conditions suitable for fish. That information would be important to figure out how to target riparian restoration efforts.

In addition, you could use aerial photography to get an idea of the riparian cover throughout each of these drainage systems, and then through the use of temperature models, you could prioritize streams for early riparian restoration. I think there's some opportunity for setting up additional long-term restoration or monitoring sites such as the L.C. (?) drainage and Carnation Creek, and so on, where you monitor adults in, smolts out. And if you are continuing that throughout a period of riparian restoration, you may have a better understanding of how the riparian or total stream condition can improve fish production. But in addition to looking at salmon, I think we need to look at resident species, because it's been shown in the Snake River Basin that the loss of salmon has been accompanied by a loss of resident trout, which indicates some real problems in freshwater habitat.

I also would recommend application of land classification systems. And in doing things like that, you could develop an understanding of the basic capacity of riparian areas to support riparian plant communities of various types. There's some good examples where this has been done in Oregon, where through use of variables such as valley type, valley gradient, climate and soils, and so on, you can relate that to the ability to have certain plant communities, willow communities, and so on. And because so many of our streams no longer have any semblance of past communities, you can use that kind of classification to figure out what would be appropriate species to replace in them.

MS. COGAN: That is a good shopping list. Anyone want to add to that or make any priorities?

DR. PEARCY: I just wanted to reemphasize what I think is the real power of the comparative approach, and that's been mentioned before with the Fraser and other systems. I don't think we just want to focus on the Columbia. We want to look at other systems that have similar life-history strategies of fish, and those that are different. And I think with this you can probably sort out ocean effects and freshwater effects in some cases, particularly comparing hatchery fish with wild fish in the same system. And I think that's really important.

Also, it was mentioned, smolts in/adults back, that's the basic information that we need to separate ocean from freshwater effects. And very little of that has been done. Carnation Creek is a good example. There are some attempts in Washington, and nothing in Oregon, as far I know, but that's the sort of thing that we really need to hone in on. And, lastly, I think that if we're talking about long-term monitoring effects, we need to get better information on the ocean conditions in the region of the Columbia plume, at least. And we have no good long-term data there. All the data that I present to other people usually comes from indices that are derived from physical factors and there's hardly any direct measurements to confirm those. And at a mini-mum we can have some sort of a buoy or monitoring system that does things automatically in the Columbia River plume for a long period of time. I think that is critical to understanding mechanisms.

DR. EMMETT: Bob Emmett, with the National Marine Fisheries Service. I wanted to follow up especially on what Bill was saying. In regard to mechanisms, I think that trying to identify how mechanisms within various habitats work for specific stocks or fish species or salmonid path life-history types is important. As you go down the whole path, what mechanisms are occurring? Because they will be different for different stocks of fish wherever you are. And that's where the mechanisms are really important; when you start looking at ocean, too.

We need to be sure we understand that there are a whole bunch of things going on in the ocean. And we may not be able to control that ocean, but if we know the mechanisms that are occurring out there, perhaps we can modify some of our management practices. For example, during this type D circulation that is occurring right now, maybe the spring chinook, for example, may be a life-history category or stock that would benefit from that circulation type, or at least not be hindered by it; whereas for the fall chinook, we can see really intensive predation rates occurring because there is no bait fish out there, or something like that. So if you had an earlier stock, I think it would make a difference. I think it's really important that we incorporate all this stuff and look for mechanisms. Then I think management can really do something.

DR. REISENBICHLER: I'll throw in my two cents worth again in support of comparing the Columbia with the Fraser system as well as other systems, and particularly for the purpose of looking at mainstem passage and mainstem survival. And I think we need to do some more work to better understand the inadvertent consequences of one of our primary restoration tools, and that is hatchery supplementation. Actually, I think I need to get busy and elaborate the model that I presented to you yesterday, try to milk as much as we can from the existing data, establish some hypotheses, and then do some additional work describing and understanding rates of genetic change, rates of naturalization, rates of domestication. And the data from steelhead probably are not as applicable to other species as we would like. Anyway, there's a large area there pertaining to hatchery supplementation effects on productivity and the carrying capacity of these populations.

DR. MOBRAND: It seems to me that what's also needed is to develop a picture of abundance, composition, distribution of fish throughout the Columbia River, maybe even off into the ocean, by looking at hatchery releases by time and place. And also maybe looking at natural production as well, to provide a way of viewing abundance as it shifts through time and space of species that may be relevant to density-dependent survival.

DR. COUTANT: I guess most of you by now know I have a concern for food and feeding and biological energetics in the system. And I really would like to see somebody tackle that. The comparison between the Hanford Reach and the Snake River, as some of you also mentioned, other good stocks versus bad stocks. I think there's a lot we can learn there. First of all, we have very little information in the estuary. I'm intrigued by the notion that we may have an EPA National Estuary Program (NEP) being organized for our estuary. And wouldn't it be nice if we could have a hand cooperatively in working with the folks who are developing that program so that whatever is done for that program fits what we need to see for salmon in the Columbia Basin?

On a more general frame, I'd like to see more interdisciplinary work. We've got engineers and hydrologists and folks out there who know their business well, and they know their side of the business a lot better than we do. I see a lot of interrelationships between flows and fish survival, and I think those folks can help us a lot. Also, I think one of you mentioned that we've got a tremendous stockpile of data. And if you look at coded-wire-tag data, now pit-tag data, USGS flow and temperature and what not data in the system, there's a lot of stuff out there. And we could do a lot better in minding that, in addition to doing the specific things we need to do. A lot of what we need is probably sitting there in somebody's tile. We are spending a lot of effort and money on the CIS (?) and Fish Passage Center and other folks who are compiling a lot of this information, and we are probably not minding it nearly as much as we should.

MR. YON: The estuary program has been established for the Columbia. I wanted to make that clear. We've already got EPA start-up grants, and we're in the process now of forming the organization, a conference agreement is what it's called. I just wanted to build upon what you are saying. We absolutely want, and the governors are demanding that we have, the involvement of all the different federal and state agencies and stakeholders in our formation of the NEP, and we definitely see salmon as a major issue. But, obviously, within the limited resources in our regulatory authority, we can't deal with all the issues of carrying capacity and survivability of salmon, But we specifically see that there may be potential water-quality impacts on the survivability of salmon. And that's one of the things I think we really need to do more research on, in particular, to know the impacts of the plume and the contaminants there on fish survivability in the ocean.

But I did want to make clear that we are starting up the NEP right now. And the governors have specifically asked the EPA to take the lead role in getting all the different federal agencies involved. And that's being handled out of Region 10.

MS. COGAN: So you see an interdisciplinary approach?

MR. YON: We have done that as part of the bi-state as best we could. We contracted with many other federal and state agencies through the studies and have gotten them involved in the steering committee and attending technical work groups. And with the amount of information that has already been collected, the amount of resources that are going in from the different federal and state agencies and other organizations, there may be enough out there. It's just that we were not working from the same template or plate in doing our research. And certainly on the water-quality side, that's been true. We haven't done any significant water-quality sampling, and that's one of the goals that we have among the different water-quality agencies. The states of Oregon and Washington EPA, USGS, we want to join together to come up with a long-term monitoring program. But in our broad view of beneficial uses, we want to see long-term monitoring for the other biological resources and habitats. We think it's critical of you to help us estimate the effectiveness of the actions that we're going to take to increase water quality and what impact they will have on the beneficial uses, because we want to increase the health of the system.

DR. BISSON: I would like to expand a little on the environmental reconstruction bullet that's already onthe list. I think it would be very useful at some point to have a more rigorous and thorough analysis of the disturbance history of the Columbia River system. And by that I mean both the anthropogenic disturbance as well as the natural disturbance history. And by that I mean going back substantially further than a century. I think .it is to our advantage to know as much as we can about the historical environment in which these populations evolved. And so I would like to know about historical patterns of wildfire and volcanism and some of the major events that shaped the system.

I think where that becomes very important from a management standpoint is when we get around to designating areas to act as refugia -- for example, in the President's forest plan, there are key watersheds that were identified in FEMAT. These are areas with good habitat where fish go very near to the top of the plate in terms of management decisions. The question and the assumption that ought to be tested is, are these key watersheds of the appropriate size? Are they spatially arrayed in an appropriate way to preserve these fish? Or maybe they are for some species and aren't for others. So those are the kinds of questions where a good knowledge of historical patterns and the patchiness of good and poor habitats would be very helpful.

MS. COGAN: Is the information there and it just has to be compiled, or do you think it's new research? I mean, people keep referring to all the stuff that's on the shelf somewhere. Have any idea, anybody? How much of this is new, and how much of it just needs to be just resurrected or reconstructed?

DR. BISSON: I'm guessing that some of it is new.

DR. BOTTOM: I would agree with that. I would echo that that's a critical thing to do. And I think we can tease certain things out, particularly in regard to landscapes and habitat kinds of things over a relatively short period of time where there's recorded history. And you can tease some things out, as people have done, even from maps and anecdotal accounts. But, particularly if you want to get the long-term kind of thing that Pete's talking about, it might involve lookin, at tree rings and fire scars and those sorts of things. Even paleoecology work like (Chatters et al. 1991, 1995) has done looking at mussels and shell middens where he's recreated a several-thousand-year history of environmental change in part of the Basin, those kinds of things are tremendously valuable.

DR. SIMENSTAD: Not to add another thing to the list, but just to make an argument for both an approach and a way to set priorities, We should, whenever we can, establish projects that give us a synthetic product. In other words, ones that we can build on for a number of purposes and objectives. One example in the Columbia River estuary is that, if we are interested in restoring a lot of that forested swamp and marsh habitat that we've lost, we actually have the ability to look, at the same time, at subyearling fry utilization, those sorts of habitats, and look at contamination. In other words, if we open up an area that's been excluded from inundation by 100+ years, we have the possibility of looking at whether contamination is a continuous source of the system or whether, in fact, we could develop uncontaminated habitat and diffuse the spread of contamination in that system by developing new habitat. So there is an example of, I hate the term "multiple use," but a multiple --

MS. COGAN: Usefulness.

DR. SIMENSTAD: -- out of a plan.

MS. COGAN: And that is a multidisciplinary effort, too, involving different talents and interests.

MR. THOMS: I was wondering if you could use a GIS, not just as a pretty-pictures machine, to analyze two or three layers at a time. Take the thing and use it, especially the cell data, the master data, use it as it was meant to be used as an analysis tool, turn the whole situation, this whole conference, basically everything that we're talking about here today, into that framework and use that as an analysis tool to get some of these answers.

MS. COGAN: How much of a tool is it? Someone else alluded to the GIS.

MR. THOMS: Dale McCullough alluded to that earlier.

DR. HARTMAN: I come back to this whole idea of a framework. And I think one of the ways that we can start attacking some of these questions and problems is to go that route. I know "modeler" conjures up a lot of bad images in many people's mind. And I don't necessarily consider myself a modeler, although some people would disagree. We have a limited amount of resources that we can use to attack these sorts of problems, and one of the ways we can get around this is to start by constructing some simple models, just looking at where we can measure mortality. One of the things we don't know is what goes on in estuary erosion and how important it is. But it may be that by looking at cumulative mortality as things migrate down the river, we can get to a measure where we say, it looks like 40% of this additional mortality occurs either in the estuaries or oceans. This may be some place we really need to look at to understand what's going on.

So I think that there are certainly spatial components to all these things. It's not a continuum from the top to the bottom in the estuary or the rivers or anything. And so I think we can use statistics as a tool -- now, of course, the statistics that are involved get really messy. But I think we can gain some insights into what areas we need to attack, where the critical gaps are in terms of our knowledge, and using a modeling approach there are a number of ways we can go about doing it.

I didn't talk to Chuck Coutant before I came here, but I called Web VanWinkle who is also involved with this individual base modeling (IBM) program at Oak Ridge National Laboratory to find out if they actually had such a model that they were using. Initially I was thinking of this as an approach, although, I think you would want to have more spatial complexity. And typically the IBMS have several boxes, e.g., you'd have a box for the river and a box for the estuary, and I think you would want to break it down further than that. But I think the point you brought up is certainly a good one.

MR. YON: I know that the EPA has been going through the process of developing an ecological assessment process. And they have selected the Columbia River as one of their pilot areas to test that. I haven't of late been able to find out what they've actually done with that, but I know they were looking at doing it, and I think they did select it. And as part of the bi-state program, we do have the Army Corps of Engineers contracted to develop a GIS map of the lower Columbia River, in terms of habitat analysis. And they also are including in the information that they are developing as part of their dredge-management and deep-channel dredging program. So they are adding *(unintelligible)* and depth information.

So the whole effort was, again, working with all the other federal and state agencies to get some money, which we did, but to ensure that this is a GIS map that can be used by others and built upon. And I agree that one of the eventual goals is to include all the bi-state water-quality data that we have, but to also start to include other fisheries and wildlife data into that so we develop an overlay for future analysis. But that is the beginning, and that could be used by other agencies.

DR. HARTMAN: What I didn't point out, and it may not be common knowledge out here, is that we are also involved with a project with several other researchers on the East Coast in the Chesapeake Bay where we are doing exactly that. One of the premises of the project is to link land-use practices ultimately to fish production. And though it wouldn't necessarily directly apply here, a lot of the same techniques and technology might be inter-changeable.

MS. COGAN: We are talking about agricultural?

DR. SIMENSTAD: I think he is referring to their involvement in the LMAR (?) project in the Chesapeake. And, in fact, we have one of the other LMAR projects in the lower Columbia River estuary, so there is some potential for cross-linkages there.

MS. COGAN: Who's running that? Who's in charge of that?

DR. SIMENSTAD: I am.

MR. YON: Are you doing the land use?

DR. SIMENSTAD: No, we are not. That's not something we have been able to cover. So that's a direct opening or gap that we could fill.

MR. YON: As part of the DEQ, we need to do that, so we should talk.

MR. ASKERN: I have some comments on consistency and continuity of information that you collect or have collected. It's our experience this year that in the in-season process, you can monitor using pit tags where the variety of fishes were coming down from all their sources. I had a marvelous opportunity to see ??? fish go from here to there. In the Snake River we could monitor the wild fish because they were not marked. All the hatchery fish were marked. But surprisingly, to everyone's chagrin, as soon as they got down to McNary Pool, we couldn't tell the wild fish from the hatchery fish, considering the mid-Columbia stocks, that hatchery and wild were not marked.

Here was an "OOPS" type of thing. In an attempt to monitor and evaluate one system of our river, we overlooked, for whatever reason, the quality of data that we would get out of the entire system. So whatever recommendations we might have for being able to measure, assess our carrying capacity, we need to do it in a consistent manner so that we can guarantee that what we do in one stream is not going to confuse what we would like to get out of the entire system.

The other part of the continuity aspect deals with what you do in years when, for a variety of reasons, you don't have the resources to continue your studies. And specifically, this next year is expected to be one in which there are not that many wild fish to be pit-tagged on the Snake River. Discussion is about whether they will or will not allow them to be tagged. And with that kind of a condition, recognizing the critical nature of their stock, that also poses a critical question as to whether you are going to be able to collect continuous sets of information. So whatever we do in the region needs to provide for a critical review of our information collection, so we can guarantee the continuity of that information.

MS. COGAN: We want to move into the next question, which is, what management actions we can take now and in the long term? And how would you define both of those? What is now, immediate, and how long is "long term" in terms of BPA?

MR. ASKERN: Well, immediate actions need to be correct. That's about all I can really say. The immediate actions need to really balance conflicting demands. Given the great deal of uncertainty, it's not easy. But whatever you commit to do regionally, you need to do. You need to commit to it before the season begins, before your hatcheries begin their grazing programs, before your snow begins melting, before your harvest begins. But the region needs to come together and make certain commitments, albeit compromises. And whether you are tweaking the system one way or the other or trying to walk a fence, if you commit to it, do it. And that applies to all the agencies and parties that are involved. There are a lot of weasels out there that want to bend the system one way or the other. But I think integrity-wise, if we can, as a region, put our agreements down in black and white for one year or multiple years and live by them in the public arena, then we will get somewhere in the end.

MS. COGAN: Long term, how long is long term at BPA? And, Nora, I'm going to ask you the same question for the Power Council.

MR. ASKERN: The immediate and long term for BPA is that we are committed to supporting our legal requirements for recovery mitigation. And if BPA is around tomorrow, we will do that as a funding agency and not as a biological expert. We are simply carrying out the wishes of the resource managers of the region. And that's what we'll do.

MR. THOMS: Some of the history of BPA is that, at least on the habitat projects, some of them have been around for between 8 and 9 years. And making progress toward habitat recovery is extremely slow, because most of the resources -- money, that is -- is not put into a project. It goes into paying salaries. And that's the reality of it. Just materials and the cost of building a fence per mile sometimes approximates $10,000 a month.

MS. COGAN: Nora, what's long- and short term? Give us some parameters here that we can be addressing.

MS. BERWICK: And you're talking about long- and short term for management actions?

MS. COGAN: Yes.

MS. BERWICK: When I initially brought up the idea of coming up with ideas for management actions that we could do right now, by that I meant things that we could start to do to reverse what we'd done to the system. And that system isn't going to be changing overnight. I mean, we are talking an easy 20 years. That, in my mind, is short term. Long term goes way beyond that. That's as short a term as I can come up with. Ten years would maybe get you something different, because you simply aren't going to be able to do the habitat restoration in anything less. You have all these different aspects and influences that man is creating and continually working on. And unless you control all these other sectors on one bit of habitat restoration, it doesn't matter how much you try to rebuild or replant or revegetate. If you still have pollutants coming down, if you still have cattle grazing, and deal with some of those other aspects, you are not going to get it done in the short term.

DR. BISSON: I agree with Nora completely on what constitutes long term and short term. I think decadal is right for sure. I'll illustrate it with an example, not in the Columbia Basin, although I think some of the data is from the Columbia Basin. But Tom Nicholson from the Oregon Department of Fish & Wildlife and Stan Gregory at OSU and

I looked at inter-annual variation in the production of wild coho smolts from a variety of "long-term studies." We took long-term studies in a very pragmatic sense to be 5 consecutive years or more of consistently gathered data. It's not long term, but it was the closest we could come. And these were populations of fish that were not hatchery fish, they were naturally spawning populations. We found as a very, very crude ball-park estimate that the inter-annual variation in wild smolt production -- as well as the density of fish during the summer when fishery biologists normally go out and count fish -- but the bottom line was if you could compute an average coefficient variation for all these studies put together for coho, it was about 50%. So if 50% is a really crude first guess at what kind of natural variability there might be from year to year, you can use the old statistical trick of asking how many years would it take to be able to detect, say, a really crude 50% difference due to a treatment at, say, a 10% level of type- 1 error, which is stuff that the statisticians do all the time.

Well, it turns out that at the very least, you need somewhere in the 30-50 year range to be able to detect a treatment difference. So I agree with your comment that decades will be necessary if we are going to actually see the signature of something we are trying to do with the fish.

DR. SIMENSTAD: I just would definitely reinforce that and talk about it in terms of our expectations. I think we need to be right up front about how long it will take to make these evaluations. We can carry that further to the issue of looking at chinook stocks, for 7 or 8 years plus, before we even know that one generation has responded. Let's take the extreme. I think we are looking at 80 to 150 years to see the final results of a restoration activity in the estuary and wetlands. Not that we won't see early responses, but to see the system essentially revert to its natural historic conditions could take that long.

DR. MCCULLOUGH: I think there are also some dangers in that concept, that could lull us into thinking that management actions that we're taking now are effective. Say, you look at Side11 and Mackintosh's pool-loss data where, if you've lost 50% of pools over a 50-year period and you're monitoring that in a short term and ascribing steady state and pool numbers to good management now, we could be pretty mistaken. It could really take quite awhile to see that we are having a negative trend. So it calls for some really radical changes in the way sediment delivery to a stream is managed. We really have an upward trend rather than static or downward.

MS. COGAN: The very nature of the public process doesn't look 80 years ahead. We look, as someone said, to the next political term of office. So it really leads us to question number three. What determinants can we look at now to know that we are on the right track? Do we have to look at this very long --just long way?

DR. COUTANT: Before we do that, I'd like to comment on some of the management needs. One of the things I think is really important is that we find refuges of residual populations. And the Hanford Reach stock is just one that we can set aside officially and call it a national salmon refuge, or something like that. But set aside these spots as a management tool, because these remnants of good populations, as the Hanford one is, will be the core of recolonization and re-establishment of the population throughout the system. So if we've got any good ones out there, let's do our best to officially set them aside so that they can be the colonizers for the future.

One of the things I'd recommend is that people take a different view of things like straying, for example. If we take the meta-population view of salmon in the Basin and we want repopulating over time, then one management tool, if you want to call it that, is to stop complaining about straying. I mean, straying is what's going to save us in the long run. Straying isn't talking about an escapee in our system. These are the fish that are doing their thing to recolonize areas and habitats that have been degraded. So we need a mental shift in looking at some of our management strategies, of looking at the exceptions as the rules that we want to be maintained. So those are two points I would make.

DR. BOTTOM: Just to follow up on part of that, I would reinforce this idea of refuges. Certainly the idea of protecting core areas is critical. You can approach it in two ways. One is those areas where we know we have healthy populations that remain. And on the habitat side, the same thing can be said for those areas where we know we have fairly good habitat now. And that's encompassed in the key watershed idea that some land-management agencies have been involved in.

I was involved in a panel that has already identified key watersheds on the east side of the Cascades throughout Oregon. That still needs to be done for Washington. I think the east side assessment is also working on that and hopefully we can come up with something consistent between the various watersheds that are recommended. But those were a mixture of criteria, not only in terms of whether the habitat was in good condition, but also whether it had stocks or species at risk, whether it had a high diversity of species, So there was a range of values encompassed in those that would be worth looking at.

But the key point to be made here, I think, is that it doesn't make much sense to spend a lot of time on our restoration types of activities if at the same time we are continuing to lose what bits of those pieces we still have left. And I think we need to take a good hard look at that and see what management prescriptions or changes need to be made to ensure that we are not continuing to erode more in our effort to try to restore things that have already been degraded.

Secondly, on the idea of straying, I think Chuck means the traditional view of straying from a hatchery point of view, which has looked at straying as a negative thing. And from an evolutionary point of view, it's how the wild fish have maintained themselves in a disturbance regime that shifted around the landscape. And in trying to develop a better understanding of how that process works, we may well need to get more information than we have in the past on just what those rates of straying are and what that means relative to habitat fragmentation. How limited is the capacity of these stocks to recolonize? And there's a lot of modeling efforts and that sort of thing, the meta-population theory tries to get at that. And I'm not sure we have the data for salmonids to very well apply those models empirically.

Turning to some management actions that we could begin in the short term, coming back to what Pete Bisson said in his talk, I think the whole area of flood-plain interactions in our tributaries and large river systems is now a critical concern, the whole large, woody debris story. I think we know enough about the importance of backwater areas, that have been sequentially lost over probably a century and a half of intensive agricultural and other development, to begin to act on that now, and I'm not sure that we have been. So the key issue may be one of "political will" that goes beyond science, but it's going to have a real, real important impact, I think, on the future of salmon. And as I mentioned before, particularly in areas outside of these key water-sheds or these headwater areas, you get down to some of the bigger water and alluvial plains where we've had higher production historically.

Some of the watershed council ideas are a way of getting the public involved. And determining who has a stake in those kinds of issues and can take ownership of recovery may be very important. It gets beyond the science, but I think it may be one of the most effective ways to build partner-ships, and at the same time develop a sense of caring about the landscape. I think we need to instill the whole idea of management in a fluctuating environment as a general concept. Right now, I think a lot of our management standards on the land, for example, are based on average or good conditions in the environment. And what we really need to be concerned with are the pinch periods, that is, when we start losing gene types and some of the resilience in the stocks. We need to manage to get them through those most severe periods, periods of drought and that sort of thing. That's when we start losing things. And I think we need to start looking at some of our standards to see if we are adequately doing that.

We might say the same thing in terms of harvest. Pete, I think, brought up the issue earlier about this notion of setting escapement levels higher, not based on a stock-recruitment curve. It's what you need to see the habitat, per se, but based on the notion that excess fish may have some other function in the ecosystem besides just a seeding effect. The feedback of that returning fish may be real important. Moreover, just the notion of a fluctuating environment, that excess during the good years that may help get us through the periods when we dive into the trough. So that may have some implications, also, as far as how we look at harvesting.

MS. COGAN: What are these measurements now? How are we going to know when we are getting there, even within this long term?

MR. ASKERN If you look at the list of actions we have here, and if we believe what Bill Pearcy has shown us in the time-series and declining resource -- where in the early part of the century we had a decline from 1920 onward due to environmental and oceanographic conditions, and a period of continuing decline that was due presumably to hydrosystem development and removal of either spawning resource or the effect of the dams and pools, and that that period of hydrosystem development corresponded to a favorable oceanographic condition, during which you should have had this rebound, good years to take the place of the poorer years -- and if we continue with what Bill was saying, we've still got the hydrosystem, we have less resiliency in the dynamics of the population. And even though we can't get a reversion of the oceanographic conditions to something that is more favorable, we may claim some responsibility for the recovery even though we haven't changed the system. And so when the oceanographic conditions revert back to that dry condition, we'll lose the stock. The,actions that we have listed here don't get addressed that well, except maybe very tangential.

Is it appropriate to talk of that scenario? What are our management actions in 20 years? Because that could reoccur. If your time scale of those oceanographic events were decadal, the patterns are overdue to recur now in a sense Do we have some appropriate management actions, assuming that is correct?

MS. COGAN: Are those management actions due now or in 20-years?

MR. ASKERN: Within the 20 years. What do we do now? Is tomorrow

when we claim credit, and after that it goes *(unintelligible)* and we lose it all.

DR. HARTMAN: Being an outsider and having no vested interest in the outcome -- I don't live out here, I don't have to worry about anybody coming and bombing my house in the middle of the night --it seems to me that we know we have big sources of mortality. We have question marks about whether we have viable stock and all the factors that are influencing that. In the short term, what we have to look at are sources of mortality that we have any control over. In this case, I think of this as the straw that broke the camel's back. Typically you have a stock that's in trouble because it's being over-fished, at least where we come from. And typically what may be a problem is some little incremental additional source of mortality through disease or something. I think that's not the case in the Columbia. But I think one thing we do have control over is fishing mortality. We see the same problem in the Chesapeake Bay with oysters, for instance. They say the problem is disease and parasites and everything else. It just befuddles me that in the face of all this, you can continue to allow a fishery to operate where you know there is additional mortality going on. I think that could be a problem here, that maybe one of the areas we need to look at is reducing fishing mortality. Because at that point in time, I don't want to go through all the numbers, but basically your fish are close to making it home, to the point of being able to spawn.

I think another area where you need to focus short-term efforts is the fact that we know there is significant mortality every time you go past a dam. And so if you are going to put money towards doing things that can reduce mortality, and I'm sure there has already been a lot of money spent in this direction anyway, look at ways you can improve the ability of these fish to survive, either coming down through the dams or going up on their way to spawn, And those would be my two immediate knee-jerk reactions to management actions that you could take.

MS. COGAN: Are you talking about commercial and recreational fishing, one or the other? We make a big differentiation out here.

DR. HARTMAN: Fishing. Along with the El Nifio effects in the ocean, there are associated climatic effects -- increasing air temperatures or lower water flows during the summer -- that would exacerbate survival conditions in the tributaries. So I think that with the forewarning of that, plus additional climatic trends toward warmer climate, I think that puts more emphasis on the importance of starting to restore riparian habitat now, because, as we've said, it's going to take at least 20 years to start getting some noticeable recovery. And, in addition, to de-emphasize or to stop headwater logging of riparian areas, which still is common. You need to get the cold water slug further downstream, and it's not going to help by continuing the way we have done.

DR. PEARCY: I just wanted to say that a parsimonious approach is to assume that the climate conditions we have today, at least in the ocean, are not going to change, let's say, in 10 years or 20 years. Most of the analyses I've seen on the recent temperature shift indicate that it is in close keeping with what you would expect with modeling on global warming. So these trends may be longer than what we've seen in the past. And as Dan Bottom alluded, it seems to me we are in a pinch period, and we should really be managing for these pinch periods and putting emphasis into restoration of the habitat so that if we do have a turnaround in ocean conditions and other things, we have a rapid recovery. I think we don't want to depend on a turnaround in ocean conditions any time in the near term. That's the reason for the pessimistic note there to end on.

MR. YON: Certainly part of our responsibility is to identify the sources of pollutants and reduce pollutants, even in the absence of knowing what direct impact it may be having on salmon. And another issue that someone asked me about yesterday is the ability to get in-stream water rights. I'm not sure about Washington, but that's certainly been a politically hot issue for most of the resource agencies in Oregon. But that could get us adequate in-stream water flow for fisheries and certainly for water quality. And I pretty much agree with all the other statements that have been made.

MS. COGAN: Is that short term, long term, or starting now?

MR. YON: It's interesting. The EPA guidelines say that we have to develop our management plan for the NEP within 3 years, so a 20-year time frame is a lot different than the political or budget realities that we have to work with. So I agree, it's going to take much longer to do these kinds of activities. But sometimes the political reality is that you end up doing it a lot quicker.

DR. COUTANT: I wanted to respond to Kyle Hartman's comment on fishing. My home is also far enough away, it probably isn't going to get bombed. That's a real situation. Striped bass on the East Coast, as many of you know, was in almost the same dire straits as the sahnon are here in the Columbia system. And some folks made some brave decisions -- Kyle and I were involved in it. And the argument was, is it the environment or is it fishing mortality that is causing the decline of the striped bass? And some folks made the decision that we just didn't have time to argue about it, that one thing we could stop in a hurry was fishing mortality, and they did. The state of Maryland essentially said, "There will be no fish taken by anyone at any time," and the Atlantic States Marine Fisheries Commission made it a coast-wide policy. And to the extent that it could be enforced by some pretty heavy enforcement action, no fish were taken by anybody at any time. And guess what? Populations came back. A lot of the environmental conditions are still there, still bad, improving a bit. So the long-term prognosis is better. But at least we've got fish out there to work with.

MS. COGAN: How long was the moratorium?

DR. COUTANT: I think the moratorium began in ‘85.

DR. HARTMAN: I think by 1992 they were already starting to have a limited recreational and commercial fishery, but, basically, by about the second or third year, the idea was to protect the stock. They had a modest year-class in 1982 and the idea was to protect them until those fish had a chance to come back and mature as females and spawn. The first year that they could potentially have come back as mature females, they didn’t have much of a year-class. The second year, they had a big year-class. And, essentially, they didn’t really want to open it up at that time, because the way it was keyed to kick in, in terms of allowing them to reopen the fishing somewhat, was a three-year running average for juvenile survey, and it had to be above some minimum level. It turned out that one year-class was so big, it bumped the 3-year running average over in one year. And so when they started reopening it, they did it very modestly in terms of what it is. And now they are having seasons of recreational fisheries that have come back to the point where they are allowing them to take a couple of fish a day for an extended period of time. And it’s fairly substantial.

I don’t necessarily think we can expect a similar success here by closing fishing, because it’s not as big a percentage of the fish mortality. But by the same token, stepping back, if you know there is mortality occurring, and it’s one of the few things we can control, then when you’ve got stocks that are all on the verge of extinction, maybe that’s something you need to consider.

DR. BOTTOM: This just brings us back to the whole idea of carrying capacity. And I think this is where it gets in our way sometimes. The carrying-capacity idea is pretty closely tied to this notion of limiting factors. And if we look at it in that very reductionist way that we have in the past, you are led down the path of saying, “This is the limiting factor and this is what we are going to do.” And that’s where, if we’ve learned anything from our history, we’ve piecemealed things to death. And so I don’t think there is going to be one action that will get us out of this. I think we need to get into the mindset that there is some plurality of things here we need to try to work with.

MS. COGAN I would like to ask Bill Mavros to read the list to us, see if we left anything out, anything we want to add.

MR. MAVROS: Management actions, what we decide as a group for immediate actions, <20-year decadal actions, we want to balance conflicting demands. Also, we want to finish commitments that we’ve already started. Finish the product, don’t just leave them there. Also, allow straying salmonids to recolonize. The meta-population concept and flood-plain interactions -- I wasn’t too clear on the whole issue of flood plains.

DR. BOTTOM: Restoring flood plains in a riparian system.

MR. MAVROS: Keep them as they are and restore them?

DR. BOTTOM: Yes.

MR. MAVROS: And manage for fluctuating environments. Management of streams. Sources of mortality, we have control over that, so we can stop fishing, commercial, recreational, and also control by catching if we can. And improve dam reservoirs, survival and passage. And also instream flow for habitat and water quality, we can improve that. Long term, >20 years, set aside salmon refugia in the Hanford Reach. We know it's successful and there are fish there. So set aside areas like that in the Columbia system where salmon can recolonize and stray into other areas. Protect habitat quality. Restore riparian habitat and don't rely on oceanic conditions. It's a black box, so we can't really model it. We haven't seen any pattern, so don't rely on good conditions in there. And also control pollutants. Anything else that we can add?

MS. BERWICK: Maybe I'm confused, but it seems to me that what you've got up there are immediate management actions and long-term management actions. I'm a little confused about the way those have been segregated, because setting aside refugia is something we can do right now. It's going to take a long time to have any reaction, but we can set it aside right now. If we don't set it aside right now, it won't be around tomorrow either.

MS. COGAN: You really need to move it into the short term as far as actions, as far as a result -- yes.

MS. BERWICK: That's what happened here in this listing. There has been a mix-up between what we want to do now, meaning start now, and the result. I mean, almost anything we do is not going to have immediate results. So I'm having trouble with this "immediate" and "long term."

MR. MAVROS: The results of long term and the results of short term, all of them, you want to start now with these?

MS. BERWICK: Well, just about. This is the question for this after-noon, though: What can we do now? Given the knowledge base that we have now, what is it that we can do as opposed to what we discussed earlier, what do we still need to do research on before we can take a step forward? This should be a list of things that we ought to be able to take a step forward on. And it may take 20, 30 years to see results, but that doesn't mean we wait 20,30 years to set up a protected area or core areas, and things like that.

What is the second one there? Protect quality habitat, restore riparian habitat. You know, again, that isn't something I would want to see starting in 20 years. In my mind, that is an immediate management action, because we can start putting some of that back.

MS. COGAN I don't know if you have any response to that, but I think we were looking at the long- and short-term results, weren't we?

DR. BOTTOM: I think she's right. They got confused in there. I view those things as what we need to get started on. I would add riparian inter-actions in these systems, together with this idea of restoring flood plain. If you look down at the estuary, another thing we can be doing is inventorying and selecting marked restoration areas that have been removed from the estuary. In particular, inter-tidal areas that are no longer part of the system that may be restorable in terms of removing tide gates and effects like that.

MR. ROGER: Just a little more perspective on this. We have our time scales a little mixed up. I think we have to look at the spatial scale, too. Given the nature of the crisis we are facing, we need to be emphasizing actions that will kick in the short term to halt the decline of these stocks or they are going to start dropping off the table. The other kind of action we have to look at pretty. seriously is what I call “broad-scale action,” that affects more than one population of fish at a time, because the effects are more widespread. Harvest and hydropower actions are two categories there. Habitat protection, if it’s applied broad-scale, can also affect more than one stock. Habitat restoration is effective on a site-specific basis; it affects fewer stocks in the broad-scale kind of remedies. There might be appropriate applications for the use of hatcheries. I’m not necessarily saying hatchery populations, but hatcheries can be used in a narrow scale to affect population by population or reintroduction. So I think we need to keep that perspective in mind when we talk about actions relative to the kind of problem we face right now.

MS. COGAN: That some actions can’t wait -- or some situations can’t wait, is that what you are saying?

MR. ROGER: Right. And we should be looking at certain classes of actions more than others in the short term.

DR. PEARCY: I didn’t hear anything about hatcheries on that list. On short-term management goals, it seems that you want to evaluate the impact of hatchery fish to wild fish. That’s something we talked about at length, and it seems to me it should be on there someplace.

DR. REISENBICHLER: I hope it’s not crucial that we get everything on this list. I don’t think we have proposed anything radically new. What I hope comes out in the final wash from this workshop and this set of panelists is a strong emphasis by managers on recognizing the reality of fluctuating environments, in the light of Bill’s dire prediction for the lack of fluctuation now for a while. And recognition of just what shape we are in because we have a poor understanding of what the mechanism is, how things work. Most people probably would not consider understanding mechanisms as a management option. Maybe I wouldn’t, either. But the serious implications of not knowing how things work means that right now we ought to be starting and continuing projects to understand things. I know that’s nothing new, but I would really like to reemphasize that.

MS. COGAN: Can we revisit the monitoring section of this? How are we going to know when we are anywhere near success, however we measure success? I mean, how can the public agencies know, how can they account to the public, to their elected officials, etc.? Anyone have any thoughts about that? And I don’t want to use the word “measurement” because that’s too precise.

DR. BOTTOM: I think in a general sense, our performance measures have been much, much too narrowly defined in the past. It’s been defined by numbers. And we really need to develop some ecologically based performance measures that get us towards measuring whether the system is becoming, in fact, more resilient, whether that diversity is there. And that's going to involve things like looking at diversity in a variety of ways. You can look at diversity in terms of the whole native fish population; you could be looking at hatchery/wild fish interactions, ensuring that your wild diversity is not being sacrificed; you could be looking at measures of habitat complexity to see if we are re-instilling the complexity that's been lost. So that means developing some performance measures that actually look at a variety of different scales, within, say, watershed or stream or landscape scale across the region to see what habitat or geomorphic types are either at risk or are restoring.

DR. PEARCY: I guess that third question is, what determinants of carrying capacity can we monitor to evaluate actions to improve salmon survival? The emphasis has certainly been on survival, and I think that's pretty difficult to measure in a lot of cases. As I said yesterday, one of the surrogates, more or less, for carrying capacity and food limitations is growth. And I don't think we've said very much about growth or looked at growth responses of fish, both in the river and the estuary and the ocean. And I would make a plea for using long-term databases that we have on scale collections and the vast information we have on Clearwater tags from hatcheries and also from wild fish. So let's look at growth rates. Growth rate is what's going to respond readily, let's say, to food limitation and to density-dependent factors, and your whole carrying-capacity issue.

So certainly, as has been done in the past with hatcheries, you can look at scales of smolts, of release, and scales of those coming back and get some information on growth rates, as well as things like size-selected mortality which can be a very powerful thing that gets at predation pressure, too. And looking at a time series, for example, of scales from one stock, from one system, and comparing that with other systems to look at where the growth may be limited and how that growth is affected by the number of fish that are in that system at that time. And I would say that growth is a fairly cheap thing to look at relative to what we are talking about, as opposed to actually measuring survival rates. And I haven't heard too much about it.

DR. SIMENSTAD: I might add that we should also bear in mind that we could use that in the short term as a proximal measure for experiments and focal studies. Using otolith microstructure, using DNA, RNA, gives a potential measure as a surrogate for survival to analyze or compare stock performance on very short-term, days-of-weeks scales. That, at least from our experience in estuarine experiments, could be productive. Of course, it ultimately needs to be coupled to long-term survival to be highly productive.

Also, I think using that in cooperation with Kyle Hartman's and Steve Brandt's approach, framing that in terms of potential scope for growth to find out what you are realizing in terms of potential, could then add a lot more power to that.

DR. HARTMAN: I don't remember who, but somebody mentioned PIT tags. Another way we might be able to look at how successful we've been in effecting changes in the habitat and how that *(unintelligible)* the growth is through some of these PIT-tag techniques. As I understand the technology, if you're monitoring upstream and then downstream, you get measures of individual growth on individual fish, Then if we do something that modifies that habitat, which we hope is for the best, that should give us over time a way of keeping track of whether those fish are now growing. We've been putting 10 million smolts in every year, and all of a sudden, now, growth rates are improving. Should give us some measure of whether what we did was, in fact, effective.

Expert Panel Recommendations to the Council

MR. NEITZEL: We have gone through the list of questions that we wanted to discuss today, and I would like to end up with a summary. I would like the panelists to look at this as an opportunity to speak to the Power Council, the Council staff, and the BPA staff. And this is your opportunity to tell them what they should do relative to carrying capacity. All the things we've talked about, how they should think about it, what research needs to be done, what management actions they can take relative to survival and carrying capacity, how it should be defined. Make them understand what you think. I'm going to ask you to go down the panel and each one of you send your message.

DR. COUTANT: It's hard to summarize all the really interesting things we've talked about in the course of the last two days. You'd have to read the transcript. Read the book, as they say. But carrying capacity is a fairly intuitive, relatively simple concept that turns out, on reflection, to be not simple at all, with a lot of complexities to it, as we've talked. There is a whole host of research questions that need to be answered if we are going to get at a lot of those complexities.

But I think one of the messages for the Council ought to be the bottom line that we come to this afternoon. That in spite of all that complexity, in spite of the "ifs, ands, and buts" we technical people can raise and the intricacies that we would like to get into, there are a number of fairly straightforward things that they can do right now in the next year to help out the stocks through the general notion of carrying capacity. Setting up refuges for stocks and habitats and many of the things that we've mentioned. I don't think we should expect the Council to understand all the ecological ins and outs that we've been talking about, but we can give them some fairly important messages about what can be done. I think with the consolidation of the notes from the meeting, we'll have a lot of those that should be useful to them.

DR. BISSON: The establishment of a region-wide network of watersheds, fourth and fifth or larger, 200 km^2, spanning a range of conditions between intensively developed to nearly pristine, both east side and west side. For each reference watershed, a 50-year monitoring plan guided by a research advisory group that includes not only scientists but interest groups and the public, so that there is ownership in what is done from an adaptive management standpoint and in what is monitored and what the costs are going to be to all of us.

However, within the monitoring program, my personal view as a scientist is that it would be very helpful to have adult salmon smolts out, a periodic habitat inventory throughout the watershed, say, every five years or event-driven in case Mt. Hood erupts, or something like that. A thorough genetic analysis, also done periodically. Because I have the gut feeling that sometime in the future we're going to want to know the genetic trends in the populations. Are we continuing to lose genetic diversity, are we getting it back. or what?

Life-history studies, as Bill mentioned and very rightly so, should be continued, including life-history patterns in small, marginal populations. Unique marks for each hatchery, because if you believe some of the recent work that has come out of the University of Washington (Claribel Coronado-Hernandez, for example, who's a Ray Hilborn student), all hatcheries are not equally successful. There is a tremendous difference between the success rates of fish in each hatchery.

And finally a strong water-quality monitoring program that includes public involvement in monitoring itself so there is ownership in how things are changing. And I think that the public is actually imminently suited to do some aspects of water-quality monitoring.

DR. REISENBICHLER: I don't have much to add to what's gone on. I have to agree with Chuck, to read the book, basically. And I will just repeat what I've said before, basically. I've heard of at least one study conducted by BPA that's being severely criticized. A large part of the criticism was because it wasn't involved in a major production program. It wasn't going to produce results in the short term. It was a study designed to answer some of these basic research questions. I simply want to stress that I think we are seeing the ramifications of not having answers to those basic questions, and that we shouldn't abort those kinds of studies in this emergency just because they are not producing fish.

And, as has been said before, I think we ought to go far beyond carrying capacity. We shouldn't be locked in by this concept of carrying capacity. Although you can bend the "carrying capacity" definition to include things like diversity, we need to worry about maintaining life history and reestablishing life-history and habitat diversity. We need to worry about productivity as well as carrying capacity and genetic quality. I can't agree strongly enough with the others in the importance of these refuge watersheds. We need to protect what still seems to be viable. And I think it's very important to recognize not only the promise but the limits and the threats of hatchery production. But as we know from the past, some people have tended to remember the promise and completely forget or disregard the limits and threats of hatcheries.

DR. MCCULLOUGH: I really support all the recommendations of the other panelists. And I guess the only thing I could add is the importance of monitoring the growth rate. I think that is a useful addition to keeping track of production in the system. Growth rate and biomass or numbers are intimately involved in the ability of these systems to produce fish.

I think in terms of survival, there is a lot of opportunity in all these areas to do research. But I think, as far as funding by organizations like BPA, that we need to remember that BPA is not like NSF (National Science Foundation). NSF is directed to be conducting research just for the pure scientific joy of it. I mean, there are a lot of needed management applications to pursuit of knowledge in this area. We don't need to be investigating carrying capacity for all its interesting ecological nuances. But we need to find ways in which habitat management is contributing to reduction and survival. And I think in many ways, we know very well what is causing some of this. I don't think there is a great need to do additional studies on the effect of fine sediment on survival emergence and so on. So I think a lot of resources could be effectively put to use in securing and restoring riparian areas, restoring entering watersheds. And rather than looking at limiting factors, address a myriad of things that go into the total integrated production of a system.

Some interesting research would be to look at the way salmon use watersheds. And I think what has been and will be found in the future is that they use many different portions of the watershed. And that spatial inter-action of habitat components really emphasizes the need to address ecosystem management and holistic watershed management.

I think the protection of particular stocks is important. That is a framework upon which to establish some monitoring of watersheds for long-term research. However, in some cases there is really a limit to what we know about the different stocks that exist out there. I think there are many opportunities to use the watershed or regional classification system. For example, a lot of life-history diversity is established according to geographic patterns and hydrologic regimes, and hydrologic regionalization is frequently shown to explain distribution of species, communities, and different production zones. And fish evolve, I think, to make use of resources during appropriate periods that are guided by the peak flows and the low flows.

DR. SIMENSTAD: I guess I would go back to the view of several people on this panel, that we need to avoid looking at carrying capacity in the traditional sense as an asymptotic value, which could be used as a target by which we would trill all the knobs we think we have to control the Columbia River in terms of managing to maximize survival. If the concept of carrying capacity has a value, I think it's in trying to understand one of the potential mechanisms that could explain why we get variable survival out of different species, races, and life-history stages in a varying environment. So I look at carrying capacity not as a management tool, but as an intellectual window onto what might control highly variable survival. But as a system, not as an estuary or a mainstem or something like that.

In terms of my specific role in looking at the estuary, I guess most of us recognize that estuaries have always been treated as a black box. And I guess I would reinforce the emerging idea that we need to look at the estuary as the continuum in a process from upper watershed to the mainstem to the ocean. And there are some good indications that key attributes of fish passage, such as residence time in the system, may be cues or important monitoring parameters to ultimate survival and performance through the ocean to return. If we are going to focus on any particular aspect in the system, I think it would be easier to pay attention to how residence time changes as a function of those different life-history elements of the populations that pass through, how that changes over time and with environmental variation. I'm not saying that residence time is manageable from our standpoint, but I think it's something that may give us, if we do see real bottlenecks, a mechanism whereby we can propose potential management actions.

DR. HARTMAN: The first thing I would like to reemphasize is that we need to make a commitment for the long term. Even though Bonneville may not know if they are going to be here tomorrow, I think we have a responsibility to the system and the resource to see this thing through. We can't expect that we are going to get results next year or even in one or two generations. It may take some time. It's not going to be like striped bass where you have multiple chances to spawn and one-year stock. So we can't look for things to happen very fast.

I think we need to look at ways of improving survival and reducing mortality any way we can. We are that close to the edge, I think, with these stocks, and that has to be a major emphasis. I think in terms of monitoring, some of the discussion we had earlier dealt with doing aerial surveys and looking at the thermograph of the water. We could use that as a tool to measure how far we've come in managing some of the riparian zones, and how we could look at it not only look from a perspective of how far we have to go to improve it, but how far we have come as it's going along.

I don't really know how to attack this whole hatchery issue. I just want to point out that we are always thinking that the hatcheries necessarily could be bad, and perhaps we are not seeing the other side of the issue, that they could have some good or mediating effects in that when you stack a bunch of salmon here -- and we are presuming they are not quite as bright as the wild fish -- they may be performing a positive function in that they may be satiating predators as they go over the dam so that more of the wild fish get through. And, also, they help to mediate some of the demands by user groups on the wild fish. So they may not be all bad, even though there is the genetic issue.

So I guess getting back to that whole idea of not looking for results right away. You probably won't hear this from scientists very often, but I think we need to take action in a lot of ways all at once. And although that is not the way we are trained scientifically -- we want to tweak one thing and wait and see what happens and see if it was effective -- I don't think we have the luxury of waiting in this case. If we do that, I think it's like buying an old car that doesn't have any spark plugs or wiring and the battery is dead, and if you just replace the battery, you find out the thing still doesn't work. And so that's kind of the analogy I have here. We should try to fix all these things at once and see if we can get the thing running. I don't care as much about why it works immediately as the fact that we get it running.

DR. PEARCY: First of all, I would like to compliment BPA and the Power Planning Council on including the estuary and the ocean. It wasn't too many years ago that BPA stated quite categorically that their responsibility for the fish ended once they left the river system. And we have seen a change in that. So I think that is certainly a good step forward.

I would like to emphasize that we need to try to separate, segregate, partition ocean effects, estuarine effects, and fresh-water effects as much as we can so that we can really evaluate what humans are doing to the river system and what the effect of that is. Right now everything is pretty much confounded, I think. And like Pete said earlier, I certainly would encourage people to undertake bold, long-term experiments in the system.

And I think I disagree a bit with what Kyle Hartman just said, because I think one of the failings that I've seen -- and I'm not really a good person to evaluate this -- is the lack of long-term experiments with adequate controls in the river system. It seems to me that's one of the things we really need, so you can find out how these actions really translate into changes in survival. And perhaps some of these things could be designed by, I hate to say it, but a *(unintelligible)* panel or committee of some sort that could help in designing these experiments, which would take some of the heat off the administrators to make these decisions, more or less, in strictly a political arena.

Finally, I think something that perhaps needs to be emphasized a little more is not the cure-all, but the role of technology. I mean, a lot of the things we do now, we couldn't have done five years ago. And the PIT tag is a good example. I was talking to Gary Johnson yesterday about improving the technology so that we could have, for example, corresponding tags. As the fish went down the river system, and even in the ocean, you could see what groups of fish are present, and where and how they are clustered, and things like that. I think that technology should certainly be encouraged to develop tag systems that could do this sort of thing. And I think we should at least look more closely at the environmental conditions in the plume and how this relates during outmigration of smolts. And one of the things that could be done there, very simply, is to fund a minor program that would look at satellite images of the plume both in chlorophyll concentrate and in sea surface temperatures, and hopefully relate that to some ongoing studies about when fish are entering the ocean.

DR. BOTTOM: I would reiterate the idea of where we've come in our thinking. Certainly we as a profession have changed our world view dramatically, just as society is beginning to change its view of the world. And our agricultural notion of how a river or an ecosystem operates no longer seems very adequate, for lots of reasons. But the most important reason is that we've seen the failure of that approach. We've tended to impose a design of nature that basically fits our economic system, and, unfortunately we failed to let the rest of the natural world in on it. I think we need to look at variation as something not to be avoided or removed, but as an organizing property of natural systems. And it is the loss of that organization that we are bemoaning today and that we need to find ways to accommodate. Variation essentially allows for diverse opportunities for diverse competitive species to evolve into niches that they wouldn't otherwise be able to take advantage of. So we always run the risk, when we try to normalize things, of that variation dropping out, whether it's stocks or diversity by the native species.

So, in short, I would look at the coevolution between various levels of biological organization and the physical environment in which they find themselves. And I would echo what I think was behind Pete Bisson's comments, that we extend that coevolution view to include ourselves and realize that, at least prior to the whole world of scientific management when we were less scientific, we were more closely coevolved with natural systems. We had certain types of informal management systems then, that we may not agree with today and may never go back to. At that stage, they somehow worked because people coevolved and coexisted with salmon for thousands of years. So we may have some things to learn from the success of early cultures that we could turn to in some analogs. Even if we don't implement them in the same way, they may have some advantages to us in looking to the future.

I would suggest that at least one way to get started in that realm is to find ways to begin to directly involve the public in making choices about the resources. Rather than providing prescriptions with unknown predictive responses, the role of the scientist will increasingly be that of an advisor and a counselor to explain, as best as we can, the alternatives and the implications of those alternatives so that people can make informed choices about the use of resources.

I would also echo the refuge idea. There has been a lot of work in the last couple of years trying to identify refuges and make suggestions for them. The downfall of the refuge idea, at least to date, is that it's predominantly based on federal lands in higher-elevation areas that are among the best remaining habitats. But those areas do not yet incorporate some of the more diverse and more disturbed types of habitats, or at least the full diversity of habitats that once existed, and perhaps some of the most productive ones for salmon historically. Our ability to really get into that area of the landscape that may historically have been responsible for the greatest proportion of salmon production, will depend on our ability to work with public groups on public lands.

And then, finally, I would reiterate the idea that as we develop performance measures of how we are doing in this, we get away from the mindset of simply looking at "doubling the run" and instead look at how we can apply some of these other measures that we've talked about here, to give us an understanding of the resilience and complexity of the system, and whether we've improved things.

DR. MOBRAND: Just a few thoughts. Presumably the reason for an interest in carrying capacity is to search for rules, guidelines for making management decisions. And I guess my first urge is, like the rest of the panel has suggested, that carrying capacity not be looked at in the traditional way but as inseparable from concepts of diversity and productivity. It needs to be looked at in a broader context.

Secondly, if there is a rationale or framework within which capacity of the parameters plays a role, and those lead to decisions, that one thing we ought to insist on is that there is a rationale for decisions that are made. That there is a logic, a series of statements that explains how a given action produces an expected result. That's the beginning of creating some scientific accountability for the process.

And then I agree with the notion of creating a reference population, or refugia. But I think that would be a risk and we will be remiss if we limit our study and analysis, and focus too many resources, simply to that. That moves, in some ways, away from the notion of diversity. I think maybe what we need to do is perhaps identify a host of indicators or probes to define life-history trajectories of a whole suite of populations. And take a look at the environment from that point of view, sort of taking the fish's perspective, but look at it from the viewpoint of many, many populations. But we need to be careful not to simplify, not to try and reduce the complexity. I think that's been part of the problem in the past.

So I would suggest as a part of this effort that we work towards understanding diversity, explore how life histories travel along the margins of the time/space landscape and what they encounter, as well as for those fish that travel the main highway in their life history. And I echo much of what Dan Bottom just said about our role as advisors in the context of resource management. I think we can help in identifying diagnostic species, indicators of environmental health. I think that so many discussions about ecosystem health tend to lose focus, tend to not go anywhere. It creates lots of interesting debate, but there needs to be some kind of focus to move towards action that would restore and improve habitat. And at least one way of doing that may be to identify a series of indicator species, diagnostic species, and pursue them with some vigor. To select them to be part of critical resources, critical populations that have value in themselves. And maybe select others, not because they are valuable in themselves, but because they may be indicators in general of the health of the system. And carry that analysis all the way through the affected environment to the ocean and back.

I think that's the main message I would have, that we need to find a focus that allows us to understand the whole life history and do that for many different populations.

MR. NEITZEL: Thank you for your summaries. Anybody else have one last question for the panel? Anything that you were expecting to hear over the last two days that you didn't hear, that you would like somebody to address? We can take a few minutes here to do that.

MR. JOHNSON: I'm Gary Johnson, with Battelle. I would like to follow up with a couple of things in the Council's program, which had about ten elements dealing with carrying capacity, and ask you for your opinions or comments on these thoughts. I realize a lot of these things need further study, but we are interested in gathering information about what you think.

One has to do with the competition between non-native species and anadromous fish. There was little mention of an interaction with shad earlier. Do you have any thoughts on that or other non-native fish? And, secondly, back to the plume -- obviously something that's not well understood -- the Council asked for an evaluation of the effects of spatial and temporal alteration of the ocean plume caused by the federal hydrosystem.

DR. COUTANT: One of the scariest things I've seen in the last week or so was an article in *The Oregonian* that some huge striped bass had been caught in Portland Harbor. These were 40-pounders or something like that. And they were some pretty proud fishermen to catch fish like that. I love striped bass, worked on them for a long time in Tennessee and the East Coast, and a little dabbling on the history of them on the West Coast. If we want to see salmon get gobbled up real fast, put them in the same habitat with a bunch of big striped bass. Their optimum temperatures are pretty close to salmon, and striped bass will eat a lot of fish. I think we may want to become concerned, although I'm not sure what we can do at this stage. But if we start getting a selfreproducing population of striped bass in the lower Columbia River, we are going to have real problems with salmon.

DR. BOTTOM: Just to add to that, the other side of these species interactions is the example of the shad that you brought up. And I would just reiterate what Si pointed out, maybe a little more explicitly. If he's correct and we have shifted that estuarine system from a macro- to a micro-detritus-based system, then trying to do shad removal might be a classic case of treating the symptom. Our past history in terms of predator-control programs is not very satisfactory, to say the least. And I think I'd look pretty hard before I launched off on a predator-control program, particularly when there was strong evidence to suggest that it was a measure of habitat change rather than a cause of any direct interaction with salmon.

DR. PEARCY: In terms of the plume, I think that talking to physical oceanographers like Ebesmeyer in Seattle, could get you a lot of information on the size, shape, and extent of the plume over various time periods. And there's some good data on that. Certainly the plume was much, much bigger, and further in extent during these wet years. In the sixties, for example, it had been measured all the way out of San Francisco. So I think that you could get a lot of data on size and shape of the plume relative to flow characteristics in the Columbia, both seasonal and peak flows and things like that. Although the physical side of that could be provided, I don't think there will be much, if any, data on the biological effects.

MR. NEITZEL: What about the effects of the hydrosystem on that plume?

DR. PEARCY: That's the peak I was referring to. Certainly this big *(unintelligible)* in the spring is no longer there. There's as much water that comes out in the winter as in the summer now. That has been detected, I guess, and modeled to a certain extent. And it's been shown to have a significant effect on the salinity all the way to Crescent City, California and probably beyond Puget Sound in the winter. In other words, its salinity now is higher down south and lower up north. The plume goes north in the winter and south in the summer.

MR. NEITZEL: Does anyone else want to address these questions?

DR. SIMENSTAD: A couple things. One, in terms of the plume dynamics, there is probably going to be some new information emerging from a study done by Barbara Hickey and David Jay at the University of Washington. And so they might be good people to address that question to, because they probably have dealt with the plume dynamics most recently. And, certainly, David Jay has the potential to add some modeling weight that could incorporate changes from the hydropower system to that question.

In terms of the exotic species introductions, I think one thing we have to realize is that we are the vectors of those introductions. And until we are willing to grapple with the resources necessary to eliminate water dumping, to eliminate movement of vessels from San Francisco Bay to Coos Bay to the Columbia River, etc., and the consequences from those, to a large degree we are going to have to put up with at least the introductions, and then decide how we are going to deal with any potential control or management if they become established.

It is important to remember that the Columbia River, like most of our estuaries in this region, is a geologically young and disturbance-driven system. They are very prone to having introduction because there are just a lot of open niches. In the case of the Columbia, not that I've looked at it intensively, it looks like the introduced species have supplemented the system. They haven't displaced anything. That's obviously not the case in San Francisco Bay and a lot of other places. So, whether that's real or not, I don't know. But if you look at introduced zooplanktors, if you look at shad, there is no case to argue that that's necessarily occurring in the estuary. And it's certainly worth investigating further.

I think looking at it, for instance, in the mainstem as competition is certainly amenable to modeling. I think a simple consumption-rate, prey-availability model can be generated to look at how much cropping effect you have with juvenile shad versus migratory salmonids. I think that's a tractable approach, at least for first approximations. As to whether or not we've modified the system and irreversibly opened up continuous introductions and establishment of exotic species, we will just have to wait and see if they really have an impact on our system. In the case of species like shad, though, I would think shad contributes more to the production of salmon in the estuary of the plume than vice versa. And I think most of the information indicates that they appear in the stomach system of salmon more than vice versa.

DR. BOTTOM: Another question that only time will tell is whether, through the decline of natural populations of salmon, we open up niches for other things. Certainly some evolutionary biologists have looked at that on an evolutionary scale and shown examples of where species have apparently gone extinct. It's opened up niches and allowed peripheral populations to expand their ranges. That's always a possibility.

MR. NEITZEL: Nora, do you have any final comments to the panel from the Council staff?

MS. BERWICK: My main comment is that I want to thank you all for coming and taking time from your schedules to talk to us about carrying capacity and helping us figure out where we go from here. Do we really think of what we need to do in terms of carrying capacity, or do we look at it as trying to get at how we do some of the reversal in terms of getting back the resiliency in the environment and in the genetic population part of it?

DR. REISENBICHLER: There was one item on one of our lists that troubled me, and that was Chuck Coutant's concern about straying. I guess I would think of straying similar to mass wasting and land slides, that there is a natural background level which is good. In fact, that's how we get our substrate for stream systems. When we increase the frequency of landslides by logging these steep upsiope areas, we increase the frequency ten-fold or something, then we start questioning whether we are doing any good. In fact, it looks pretty clearly like we are doing some harm. And I'm sure Chuck meant it no other way. Just simply use some common sense when thinking about straying. Straying in and of itself is not bad, but highly accelerated or exaggerated levels of straying may well be bad.

DR. COUTANT: I agree.

DR. HARTMAN: This is not necessary related to the conference, but I mentioned to you early on that I thought this whole workshop process would be helpful in terms of education, fish ecology and fish management courses, that type of thing. I thought I would ask the other members for their opinion about whether you would be willing to ultimately allow this videotape to be used for educational purposes. I think that you seldom have this kind of opportunity to hear this many people speaking about a similar system and all the complexities. I think it would be a great educational tool. I would be happy to use it in a course that I'd be teaching. And so I'd like to remind everybody that I had asked that and see what their thoughts were.

DR. COUTANT: What are the royalties you're willing to pay?

DR. HARTMAN: This is for the good of humanity.

MR. NEITZEL: In closing, then, I would like to say that I feel you've all accomplished what we need to continue our work. Our schedule is that we will draft a study plan to the Bonneville Power Administration this fall, and that will be presented to the Council staff before the end of this calendar year. We have recorded what has been said here. One of our products to BPA, separate from the information for the draft study plan, is a workshop proceedings. We will summarize all this and put it in a document for BPA that will be available to you.

Chapter 5: CONCLUSIONS AND RECOMMENDATIONS

The workshop proceedings reported here are results of one task completed in pursuit of the answers asked in Measure 7.1A of the Council's Program (NPPC 1994). The conclusions and recommendations that we report in this section are the conclusions and recommendations that the authors came to after completing their evaluation of carrying capacity (Neitzel and Johnson 1996a) and study plan for evaluating carrying capacity (Neitzel and Johnson 1996b). We used the information we learned from the experts at the workshop in developing these conclusions and recommendations. **The following conclusions and recommendations should not be ascribed to the expert panel, the steering committee, or BPA and Council staff. These are our conclusions and recommendations.**

To pursue the capacity parameter as a single number or set of numbers that quantifies how many salmon the basin or any part of the basin can support, will not provide useful information to meet the objective of Measure 7.1A. This is the mechanistic view of salmon population dynamics and it will not work. The region "must *recognize andprotect...diversity...It is not enough to focus only on the abundance of salmon*" (NRC 1995). We have to realize the quality of whatever happens to be at the present time. Then, significance lies in the purpose of what we are pursuing. Bella (1995) describes the need to move toward a "*healthy environment strategy.*" He claims , that the assessment and management of the many activities responsible for the decline of salmon in the Pacific Northwest are hindered by fundamental misconceptions. Management and policy have been dominated by presumptions that fail to grasp the complexity of human and salmon interactions (Bella 1995). To increase our understanding of ecology, carrying capacity, and limiting factors that influence salmon survival under current conditions, we must deal with the complexity of issues such as carrying capacity. In closing, we conclude and recommend that:

- Strong inference (Platt 1964) is needed to evaluate carrying capacity in the Columbia River Basin. All proposed research and proposed management actions should include the steps defined by Platt (1964): devise alternative hypotheses; devise experiments, with alternatives, to exclude one or more of the hypotheses; carry out the experiment or action to get clean results; recycle this procedure.
- Carrying capacity is a complex concept that can be evaluated from a contextual point of view that is consistent with observations of salmon populations and can be used to develop a study plan to increase the region's understanding of ecology, carrying capacity, and limiting factors for salmon. The Council and BPA should use a contextual view to evaluate carrying capacity.
- From the contextual view, capacity is a component of salmon performance, and is inseparable from diversity and productivity. Capacity reflects the quality and the quantity of salmon and provides us with a relative measure of the size of a

population[6] . The Program should incorporate the complex, interdependent relationship of diversity, productivity, and capacity into all the measures.

- Understanding capacity from a mechanistic view, the basis for Measure 7.1 A and much of the Program, could be useful for making a list of determinants, however, this view is not consistent with the complex nature of salmon life histories and Columbia River environs. The mechanistic view is not useful for developing a study plan. The mechanistic view of salmon in the Columbia Basin should not be used in the Program.
- The Patient-Template Analysis is a tool that could be used to evaluate carrying capacity and develop a study plan to increase our understanding of the ecology, carrying capacity, and limiting factors for salmon. The Council should call for a Patient-Template Analysis, as described by Lichatowich et al. (1995). The region will be able to evaluate carrying capacity under current conditions, compare current conditions to historic conditions and thus, predict possible future conditions for salmon in the Columbia River Basin.

In closing, Measure 7.1A is a microcosm of the entire Program. It is based on a framework[7] that is not working. The carrying capacity measure and the Program as a whole need a new framework. The new framework should be based on the recognition and protection of the entire life cycle of salmon and not on abundance of salmon alone. The framework should be consistent with observations of salmon populations and incorporate the complexity of the population's attributes. The framework must accommodate the connectivity among life stages and the interrelationships among capacity, diversity, and productivity within the Pacific Northwest ecosystem. The contextual view provides the basis for a new framework.

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[6] Population size is not different from the mechanistic definition. What distinguishes capacity when it is defined in a contextual or historic event framework, is its inseparable link to diversity and productivity within a measure of performance for salmon. For further clarification of salmon performance we suggest Mobrand et al. (in press).

[7] During most of this report, we discuss definitions, hypotheses, and views. When we discuss the need for a new framework, we mean to use a broader term. We include three elements, when we use the word framework: theory, tasks and tools. The theory is the general proposition or principle we use to explain the events we observe. Theory results from our view of the ecosystem and the hypotheses that we test. The tasks are the commitments, processes, and institutional requirements needed to carrying out the Fish and Wildlife Program. The tools are the instruments of management needed to analyze data, schedule projects, resolve conflicts, and make sure our actions are moving us toward our objectives.

CHAPTER 6: REFERENCES

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